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# Light Attenuation in the Mixed-Layer of Lakes in the Experimental Lakes Area, 1969-1990 Data

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# Table of Contents


| | Page |
|---|---|
| Abstract/Résumé | iv |
| Introduction | 1 |
| Studied Lakes | 1 |
| Methods | 1 |
| Results | 2 |
| Discussion | 3 |
| Unmanipulated lakes | 3 |
| Manipulated lakes | 3 |
| References | 4 |


## List of Tables


| *Table* | | *Page* |
|---|---|---|
| 1 | Summary of morphometric characteristics of the lakes. | 6 |
| 2 | Mean vertical attenuation coefficients for each lake and year. | 7 |
| 3 | Coefficients of variation of vertical attenuation coefficients for each lake and year. | 8 |
| 4 | Total number of light profiles measured in each lake and year. | 9 |


## List of Appendices


| *Appendix* | | *Page* |
|---|---|---|
| 1 | Graphical presentation of vertical attenuation coefficients in the mixed-layer of 50 ELA lakes between 1969 and 1990 | 10 |

# Abstract

FEE, E.J., E.U. SCHINDLER, J.A. SHEARER, E.R. DEBRUYN, AND D.R. DECLERCQ. 1991. Light attenuation in the mixed-layer of lakes in the Experimental Lakes Area, 1969–1990 data. *Can. Data Rep. Fish. Aquat. Sci.* 850: iv + 59 p.

Light attenuation as a function of depth has been measured in 52 ELA lakes for periods as long as 22 years (1969 to 1990; 3507 light attenuation depth profiles). The attenuation coefficient (defined as slope of the line describing the logarithm of light plotted as a function of depth) was calculated for data points in the mixed-layer (epilimnion) of each depth profile. These coefficients are plotted as functions of time; one lake is shown per graph, and common axes are used for all graphs to facilitate comparisons. The result is a concise summary of a massive database, showing the quantity of data available for each lake, how transparency differs among lakes, and how transparency varies within each lake over time in response to whole-lake manipulation experiments and/or natural variability.

**Key words:** limnology; light attenuation; light extinction; transparency; long-term trends; physical limnology; natural variability; long-term monitoring

# Résumé

FEE, E.J., E.U. SCHINDLER, J.A. SHEARER, E.R. DEBRUYN, AND D.R. DECLERCQ. 1991. Light attenuation in the mixed-layer of lakes in the Experimental Lakes Area, 1969–1990 data. *Can. Data Rep. Fish. Aquat. Sci.* 850: iv + 59 p.

L'atténuation de la lumière en fonction de la profondeur a été mesurée dans 52 lacs de la RLE pendant des périodes atteignant 22 ans (de 1969 à 1990; 3507 profils d'atténuation de la lumière en fonction de la profondeur). Le coefficient d'atténuation, défini comme étant la pente de la droite décrivant le logarithme de la lumière en fonction de la profondeur, a été calculé pour des points de la couche de mélange (épilimnion) de chaque profil. Des diagrammes de ces coefficients en fonction du temps sont établis pour chaque lac; les axes sont les mêmes pour tous les graphiques, ce qui facilite les comparaisons. Le résultat est un résumé concis d'une base de données imposante; il indique la quantité de données disponibles pour chaque lac, les écarts de transparence d'un lac à l'autre, les variations temporelles de transparence dans chaque lac à la suite d'expériences de manipulation de l'ensemble du lac et (ou) en raison de la variabilité naturelle.

**Mots-clés:** limnologie; atténuation de la lumière; extinction de la lumière; transparence; tendances à long terme; limnologie physique; variabilité naturelle; surveillance à long terme

## Introduction

This report presents a graphical summary of mixed-layer light attenuation coefficients of lakes at the Experimental Lakes Area (ELA; Johnson and Vallentyne 1971). Between 1969 and 1990 a total of 3507 light attenuation depth profiles were measured in 38 unmanipulated (i.e., reference) and 14 experimentally manipulated lakes. Table 1 presents the general limnological characteristics of these lakes, which range in surface area from 1.7 to 1330 hectares, in maximum depth from 1.8 to 167 meters, and in (watershed area/lake area) ratio from 1.5 to 625; the color of the lakes varies from nearly blue (essentially uncolored) to deep brown (humic).

Light attenuation data have been routinely collected at ELA primarily because this information is required for estimating *in situ* rates of phytoplankton photosynthesis with the method developed at ELA (Shearer et al. 1985, Fee 1990). However, light attenuation is a fundamental physical property of lakes, and these data are potentially relevant to a much broader range of topics, including assessing the effects of year-to-year changes of climatic variables, determining the magnitude of natural variability in different kinds of lakes, assessing the effects of various whole-lake manipulation experiments, aiding in the selection of lakes for future whole-lake experiments, and investigating relationships between transparency and mixing depth. We hope that the concise visual summary presented in this report will facilitate such uses of this unique database.

## Studied Lakes

All light attenuation measurements reported here were made during the ice-free season. The frequency of measurement on any specific lake varied from only once on Lakes 99, 161, and 310 to twice weekly in Lake 239 in 1988 and 1989. Because they are subject to more rapid changes in transparency, experimentally manipulated systems were usually monitored more frequently than unmanipulated lakes; Cruikshank (1984, 1986, 1991) presented detailed descriptions of these experiments. Manipulations performed in 1990 that are not described in those reports are:

- Lake 227: eutrophication experiment modified, with phosphorous being added as before, but nitrate additions being discontinued.
- Lake 223: acidification recovery continued, with sulphuric acid being added to maintain the lake at a pH of 5.9 (target pH was 5.8).
- Lake 302S: acidification experiment continued, with sulphuric acid being added to maintain the lake at pH 4.5.
- Lake 302N: acidification experiment continued, with hydrochloric acid being added to achieve a pH of 5.2 (target pH 5.1 to 5.3); sodium nitrate and sodium sulfate were added to achieve target concentrations of 350 $mg \cdot L^{-1}$ $NO_3^-$ and 7.5 $mg \cdot L^{-1}$ $SO_4^{2-}$, respectively.
- Lake 382: cadmium loading experiment continued, 1438 g Cd added.

## Methods

Two fundamentally different types of instruments were used to measure light attenuation as a function of depth. In the early years (1969 through 1973), an instrument manufactured by Whitney-Montedoro and containing a cadmium sulfide cell was used; this instrument measured the total *energy* in the 400–700 nm waveband (Reid et al. 1975). In all subsequent years, instruments manufactured by LI-COR and BioSpherical and containing silicon cells were used; these instruments measured the total *number of quanta* in the 400–700 nm waveband.

From 1974 to 1978 a LI-COR 192S sensor (cosine-corrected flat-plate collector) and 185 meter (analog readout) were used (Shearer 1976). In 1979, the 192S sensor was used during May, most of June, and at the end of the

season, and a 193S sensor (spherical sensor) was used between late June and mid-October; output from both sensors was recorded on 185 meters. Shearer and DeClercq (1980) reported that there were no major differences in underwater light attenuation between these two sensors in this year. In 1980, the 192S/185 sensor/meter combination was used for routine measurements, and occasional comparisons were made with two spherical collectors (LI-COR 193S and Biospherical Instruments QSP 200). Shearer and DeBruyn (1981) report which profiles were taken with each instrument; they concluded that all three instruments gave similar light attenuation results. In 1981 and 1982 the 192S/185 sensor/meter combination was again used exclusively. Starting in 1983, the 192S/185 was used interchangeably with a LI-COR 192SB/188 sensor and meter. The 192SB is identical to the 192S apart from having a calibrated connector that permits it to be used with any LI-COR meter, whereas each 192S is calibrated for a specific 185 meter. The 188 differs from the 185 only in that it is a digital instead of an analog meter. After 1987, a LI-1000 Datalogger (digital readout) was frequently used as the meter for the 192SB sensor.

The mixed-layer *vertical attenuation coefficient* ($K_d$, units $m^{-1}$; $\eta''$ in the notation of Hutchinson 1957, which contains a useful discussion of how this parameter differs from other light-attenuation parameters) is defined as the slope of the straight line obtained by plotting the logarithm of light intensity (dependent variable) as a function of depth (independent variable). $K_d$ was calculated with a computer program written in Turbo Pascal which displayed the data graphically on the computer screen along with the statistically fit straight line (linear regression) relating these variables; individual data points that deviated obviously from this line were manually identified to the program and were excluded from the calculation of $K_d$. The values reported here are thus unaffected either by anomalous data points which frequently occur near the air/water interface (wave action makes it difficult to measure light accurately in this zone), or by nonuniform distributions of phytoplankton below the mixed layer (Fee 1976) which can cause light attenuation there to deviate markedly from the mixed-layer value (Fee, Shearer, DeClercq 1978; Shearer et al. 1987).

Raw data (tables and graphs of light vs. depth) and $K_d$ were previously published for the period 1969–85 (Reid, et al. 1975; Shearer 1976; Shearer and DeClercq 1976, 1977, 1978, 1979, 1980; Shearer and DeBruyn 1981, 1982, 1983, 1987). Copies of some of these reports are no longer available, and there are no plans to produce similar reports for later years. Investigators who wish to work with the data further should contact the senior author, who can supply the complete light vs. depth database as well as a database containing the derived mixed-layer attenuation coefficients on electronic media. Users with access to older reports should note that all previously reported values of $K_d$ were based on all available data in each dataset; because in the present report these datasets were "trimmed" before calculating $K_d$ (in order to obtain values representative only of mixed-layer conditions; see previous paragraph), values reported here may differ from those in older reports.

## Results

The mixed-layer attenuation coefficients are presented as graphs in Appendix 1 (one lake per page). Because data were only collected during the ice-free season, the time axis within individual years is expanded; the vertical line marking the start of the year is April 1, and the vertical line marking the end of the year is December 1. Whole-lake manipulations and major forest fires are identified directly on the graphs. Graphs are not presented for several lakes in which very few measurements were made; these results are presented in the following table.

| Lake | Date | $K_d$ |
|---|---|---|
| 099 | 20 August 1969 | 0.92 |
| 103 | 10 September 1973 | 1.95 |
| 103 | 26 September 1973 | 1.81 |
| 103 | 01 November 1973 | 1.44 |
| 161 | 20 August 1969 | 0.19 |
| 310 | 16 September 1969 | 1.41 |

Tables 2–4 summarize statistical results by lake and year: Table 2 contains annual means, Table 3 contains coefficients of variation (100×standard deviation/mean), and Table 4 contains the total number of measurements.

## Discussion

### Unmanipulated lakes

Annual means of $K_d$ in unmanipulated lakes varied from around 0.2 in large, ultraoligotrophic lakes (161=Hillock and 228=Teggau) to 2.1 in small, dystrophic (humic) lakes (225 and 661).

Long time-series are available from four unmanipulated lakes (224, 239, 240, and 305). There were two strikingly different patterns of variation of $K_d$ with time in these four lakes: in the first, the trend with time was either not statistically significant (lake 305) or significant but with a very low slope ($b$) (lake 224: $b = -.0033\,\mathrm{yr}^{-1}$, $n = 126$, $t = 4.99$); in the second, the trend with time was highly significant and the slopes were appreciable (lake 239: $b = -.0173\,\mathrm{yr}^{-1}$, $n = 365$, $t = 23.51$; lake 240: $b = -.0128\,\mathrm{yr}^{-1}$, $n = 145$, $t = 10.82$)[1]. It is probably not coincidental that the basins of those lakes in which transparency increased (239 and 240) were extensively burned in 1974 and again in 1980, while the basins of those lakes where transparency remained unchanged (224 and 305) escaped these fires (except for a very small part of the 305 basin). A plausible chain of events linking forest fires with increased transparency is that the flux of dissolved organic carbon (DOC) from the terrestial basin to downstream lakes declines after a fire; as DOC concentrations in the lake decline, transparency increases. Confirmation of this theory awaits calculation of DOC loadings to lake 239, but it is well established that DOC concentrations in lakes 239 and 240 decreased in synchrony with transparency increases in these lakes, while during this same period DOC remained unchanged in lakes 224 and 305 (FWI chemistry lab., unpubl.). The notion that forest fires are causally linked with increasing transparency in downstream lakes is further supported by data from lake 383, which is the only other unmanipulated lake in which $K_d$ was measured both before and after a forest fire; just as in lakes 239 and 240, transparency increased in lake 383 in each year following the 1974 fire.

$K_d$ data from lakes 239, 240, 224, and 305 also show that transparency changed gradually (if not exactly linearly) over time in unmanipulated lakes during the 22 year period for which data are available. That is, there are no "jumps" that coincide with the dates when different instruments were used. Taken together with the fact that unmanipulated lakes showed different trends over time, these results support the conclusion that the various instruments used to measure $K_d$ all gave comparable results.

### Manipulated lakes

Summer additions of phosphorus and nitrogen to the epilimnia of lakes 227 and 226N caused massive phytoplankton blooms (Fee 1979, Schindler 1988), which caused $K_d$ to be both higher and more variable than in unmanipulated lakes. Curiously, when lakes 303 and 304 were similarly treated, $K_d$ was not as obviously affected.

All lakes that were experimentally acidified (114, 223, 225, 302N, and 302S) increased in transparency ($K_d$ declined); Shearer et al. (1987) concluded that this was a direct consequence of acidification in lake 223, and discuss the problem of differentiating this experimental effect from the trend of decreasing $K_d$

[1] Trends of $K_d$ with time in 239 and 240 are not independent because lake 239 drains into 240 (it contributes about one-third of the water budget of 240; K. Beaty, pers. comm.).

that occurred simultaneously in some unmanipulated lakes of the region (discussed above).

Other experimental manipulations that had no obvious effect on $K_d$ were: summer additions of only phosphorus to the epilimnion of lake 261; summer additions of nitrogen and carbon to the epilimnion of lake 226S; summer additions of nitrogen and phosphorus to the hypolimnion of lake 302N; winter additions of nitrogen and phosphorus to lake 230; piscivore transfers from lake 222 to lake 221; and cadmium additions to lake 382.

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Table 1. Summary of morphometric characteristics of the lakes in which light attenuation was measured. Watershed areas do not include the area of the lake. Data are from Cleugh and Hauser (1971) and G. McCullough (unpublished). N/A=data not available. *=experimentally manipulated lake; see the figures in Appendix 1 for details.

| Lake | Lake Area ($A_0$, ha) | Watershed Area ($A_d$, ha) | $A_d/A_0$ | Maximum Depth (m) |
|---|---|---|---|---|
| 93 | 7.9 | 33.1 | 4.2 | 10.3 |
| 99 | 6.5 | 20.5 | 3.2 | 7.6 |
| 103 | 2.3 | 40.7 | 17.7 | 4.2 |
| 109 | 14.4 | 27.6 | 1.9 | 10.0 |
| 110 | 5.9 | 28.1 | 4.8 | 13.0 |
| 111 | 9.9 | 329.1 | 33.2 | 30.0 |
| 114* | 12.1 | 44.9 | 3.7 | 5.0 |
| 120 | 9.3 | 49.7 | 5.3 | 19.0 |
| 127 | 4.7 | 20.3 | 4.3 | 5.2 |
| 129 | 4.5 | 36.5 | 8.1 | 5.4 |
| 130 | 7.6 | 112.4 | 14.8 | 5.7 |
| 132 | 7.2 | 42.8 | 5.9 | 8.4 |
| 149 | 28.0 | 90.0 | 3.2 | 4.2 |
| 161 | 1007.0 | 1477.0 | 1.5 | 117.0 |
| 164 | 15.3 | 4791.7 | 313.2 | 6.6 |
| 165 | 11.4 | 4663.6 | 409.1 | 4.8 |
| 221* | 8.9 | 73.1 | 8.2 | 5.4 |
| 222* | 17.5 | 60.5 | 3.5 | 5.4 |
| 223* | 30.2 | 245.8 | 8.1 | 11.2 |
| 224 | 25.4 | 86.6 | 3.4 | 16.7 |
| 225* | 5.6 | 25.4 | 4.5 | 1.8 |
| 226* | 21.8 | 55.2 | 2.5 | 12.2 |
| 227* | 5.0 | 44.0 | 8.8 | 10.0 |
| 228 | 1330.0 | 5151.0 | 3.9 | 167.0 |
| 230* | 1.7 | 6.3 | 3.7 | 13.6 |
| 239* | 56.1 | 338.9 | 6.0 | 30.4 |
| 240 | 44.1 | 688.9 | 15.6 | 13.1 |
| 241 | 1.8 | 23.2 | 12.9 | 12.5 |
| 260 | 32.4 | 133.6 | 4.1 | 14.6 |
| 261* | 5.6 | 28.4 | 5.1 | 9.6 |
| 262 | 84.2 | 1144.8 | 13.6 | 30.0 |
| 265 | 13.1 | 178.9 | 13.7 | 18.6 |
| 302* | 23.7 | 66.3 | 2.8 | 13.8 |
| 303* | 9.9 | 66.1 | 6.7 | 2.5 |
| 304* | 3.6 | 5.4 | 1.5 | 6.7 |
| 305 | 52.0 | 246.0 | 4.7 | 32.7 |
| 310 | 49.7 | 489.3 | 9.8 | 19.7 |
| 373 | 29.1 | 53.9 | 1.9 | 21.0 |
| 374 | 485.0 | 1779.0 | 3.7 | 30.0 |
| 375 | 23.9 | 207.1 | 8.7 | 26.0 |
| 377 | 27.7 | 2002.8 | 72.3 | 17.5 |
| 382* | 37.3 | 160.7 | 4.3 | 11.9 |
| 383 | 5.2 | 40.8 | 7.8 | 9.4 |
| 384 | 6.3 | 57.7 | 9.2 | 3.3 |
| 442 | 16.3 | 168.4 | 10.3 | 17.8 |
| 622 | 41.0 | 378.0 | 9.2 | 30.0 |
| 623 | 38.6 | 612.4 | 15.9 | 21.0 |
| 629 | 63.1 | N/A | N/A | 18.0 |
| 661 | N/A | N/A | N/A | N/A |
| 938 | 19.2 | 12001.8 | 625.1 | 6.0 |

Table 2. Mean vertical attenuation coefficients for each lake (rows) and year (columns).

| | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 093 | | | | | | | | | | | | | | | | 0.74 | | | | | | |
| 099 | 0.92 | | | | | | | | | | | | | | | | | | | | | |
| 103 | | | | | 1.73 | | | | | | | | | | | | | | | | | |
| 109 | | | | | | | | | | | | | | | 0.39 | 0.38 | 0.43 | 0.42 | 0.36 | 0.40 | 0.41 | |
| 110 | | | | | | | | | | | | | | | 0.49 | 0.45 | 0.55 | 0.53 | | | | |
| 111 | | | | | | | | | | | | | | | | 0.49 | | | | | | |
| 114 | 0.80 | | 0.91 | | | 0.66 | 0.60 | | | 0.96 | 0.76 | 0.71 | 0.73 | 0.71 | 0.65 | 0.58 | 0.67 | 0.67 | 0.46 | 0.56 | | |
| 120 | 0.56 | | 0.60 | 0.59 | | 0.66 | | | | | | | | | | | | | | | | |
| 127 | | | | | | | | | | 0.55 | | | | | | | | | | | | |
| 129 | | | 1.33 | 1.77 | | | | | | 1.22 | | | | | | | | | | | | |
| 130 | | | | | | | | | | 0.58 | | | | | | | | | | | | |
| 132 | | | | | | | | | | 0.56 | | | | | | | | | | | | |
| 149 | | | | | | | | | | | | | | | | | | | 0.69 | 0.67 | 0.70 | 0.62 |
| 161 | 0.19 | | | | | | | | | | | | | | | | | | | | | |
| 164 | | | | | | | | | | | | | | | | | | | 0.98 | 0.88 | 0.86 | 0.91 |
| 165 | | | | | | | | | | | | | | | | | | | 0.87 | 1.15 | 1.11 | 1.19 |
| 221 | | | | | | | | | 1.06 | | | | | | | | 1.62 | 1.19 | 1.07 | 1.14 | 1.01 | 1.00 |
| 222 | | | | | | | | | 1.01 | | | 1.00 | 1.15 | 1.33 | 1.12 | 1.04 | 1.60 | 1.20 | 1.01 | 1.11 | 1.10 | 1.10 |
| 223 | | | | | | 0.48 | 0.43 | 0.43 | 0.33 | 0.38 | 0.35 | 0.32 | 0.35 | 0.45 | 0.34 | 0.34 | 0.52 | 0.36 | 0.34 | 0.33 | 0.33 | 0.29 |
| 224 | | | | | | 0.30 | 0.27 | 0.25 | 0.24 | | | | 0.24 | 0.25 | 0.23 | 0.22 | 0.28 | 0.24 | 0.22 | 0.21 | 0.24 | 0.22 |
| 225 | | | | | | | | | | | | | | | | 1.85 | 2.13 | 1.90 | 1.38 | | | |
| 226N | | | 0.52 | | 0.76 | 1.00 | 0.81 | 0.73 | 0.80 | 0.98 | 0.86 | 0.83 | 0.61 | 0.68 | 0.66 | 0.62 | 0.76 | 0.67 | 0.59 | 0.59 | 0.59 | 0.59 |
| 226S | | | | | 0.60 | 0.63 | 0.62 | 0.62 | 0.70 | 0.63 | 0.59 | 0.68 | 0.62 | 0.67 | 0.64 | 0.60 | 0.72 | 0.66 | 0.61 | 0.57 | 0.62 | 0.61 |
| 227 | 1.34 | 1.23 | 1.18 | 1.95 | 1.63 | 1.49 | 1.09 | 0.97 | 1.16 | 1.33 | 1.97 | 2.04 | 1.38 | 2.00 | 1.39 | 1.44 | 1.55 | 1.41 | 1.99 | 1.38 | 1.54 | 1.43 |
| 228 | | | 0.20 | 0.18 | | | | | | | | | | | | | | | | | | |
| 230 | 1.02 | | 0.89 | 1.07 | | | 0.86 | 0.96 | | | | | | | | | | | | | | |
| 239 | 0.83 | 0.85 | 0.89 | 0.76 | 0.82 | 0.78 | 0.76 | 0.71 | 0.69 | 0.76 | 0.78 | 0.68 | 0.66 | 0.64 | 0.59 | 0.49 | 0.66 | 0.59 | 0.55 | 0.53 | 0.58 | 0.46 |
| 240 | 0.77 | 0.76 | 0.71 | 0.67 | | 0.69 | 0.66 | | 0.64 | | | | | | 0.57 | 0.52 | 0.66 | 0.64 | 0.49 | 0.48 | 0.51 | 0.43 |
| 241 | 2.03 | | 1.57 | | | | | | | | | | | | | | | | | | | |
| 260 | | | | | | | | | | | | | | | | | 0.56 | 0.53 | | | | |
| 261 | | | 0.86 | 1.10 | 1.04 | 1.08 | 1.05 | 1.03 | 0.99 | | | | | | | | | | | | | |
| 262 | | | | | | | | | | | | | | | | | | | 0.43 | | | |
| 265 | | | 0.55 | | | | | | | | | | | | | | | | | | | |
| 302N | 0.41 | | 0.64 | 0.61 | 0.61 | 0.66 | 0.69 | 0.67 | | 0.60 | | 0.57 | 0.52 | 0.68 | 0.62 | 0.57 | 0.70 | 0.59 | 0.56 | 0.49 | 0.47 | 0.45 |
| 302S | | | | 0.59 | 0.58 | 0.59 | 0.52 | 0.51 | | 0.47 | | 0.58 | 0.48 | 0.48 | 0.43 | 0.44 | 0.51 | 0.48 | 0.44 | 0.40 | 0.39 | 0.47 |
| 303 | 0.98 | 0.88 | 0.79 | | | 0.80 | 1.15 | 1.17 | | | | | | 0.90 | | 1.40 | 1.30 | 0.67 | | | | |
| 304 | 0.99 | 1.33 | 1.41 | 1.41 | 1.08 | 0.92 | 1.06 | 1.17 | 1.16 | | | 1.04 | | 1.16 | | 0.95 | 1.21 | 1.03 | 0.92 | 0.96 | 0.95 | |
| 305 | 0.33 | | 0.35 | | | 0.35 | | | | | | | | 0.37 | 0.30 | 0.31 | 0.39 | 0.37 | | | | |
| 310 | 1.41 | | | | | | | | | | | | | | | | | | | | | |
| 373 | | | | | | | | | | | | | | | 0.28 | 0.27 | 0.31 | 0.34 | 0.27 | 0.30 | 0.31 | 0.29 |
| 374 | | | | | | | | | | | | | | | 0.34 | 0.32 | | 0.36 | 0.34 | 0.24 | 0.36 | |
| 375 | | | | | | | | | | | | | | | 0.45 | | | 0.47 | 0.37 | 0.37 | 0.41 | 0.43 |
| 377 | | | | | | | | | | | | | | | | | | | 0.44 | 0.40 | 0.49 | 0.45 |
| 382 | | | | | | | | | 0.56 | 0.61 | 0.59 | 0.53 | | 0.64 | 0.56 | 0.53 | 0.77 | 0.63 | 0.52 | 0.54 | 0.60 | 0.45 |
| 382B | | | | | | | | | | 0.91 | 0.91 | 0.83 | | 0.92 | 0.69 | 0.73 | | | | | | |
| 383 | | | | | | 0.98 | 0.81 | | | 0.74 | 0.74 | | | | | | | | | | | |
| 384 | | | | | | | | | | 0.80 | | | | | | | | | | | | |
| 442 | | | | | | | | | | | | | | | | | | | 0.39 | 0.42 | 0.49 | 0.47 |
| 622 | | | | | | | | | | | | | | | 0.51 | | | | | | | |
| 623 | | | | | | | | | | | | | | | 0.47 | 0.43 | 0.50 | | | | | |
| 629 | | | | | | | | | | | | | | | 0.55 | 0.50 | | | | | | |
| 661 | | | | | | | | | | | | | | 2.14 | | | | | | | | |
| 938 | | | | | | | | | | | | | | | | | | | 0.49 | 0.56 | 0.42 | 0.43 |

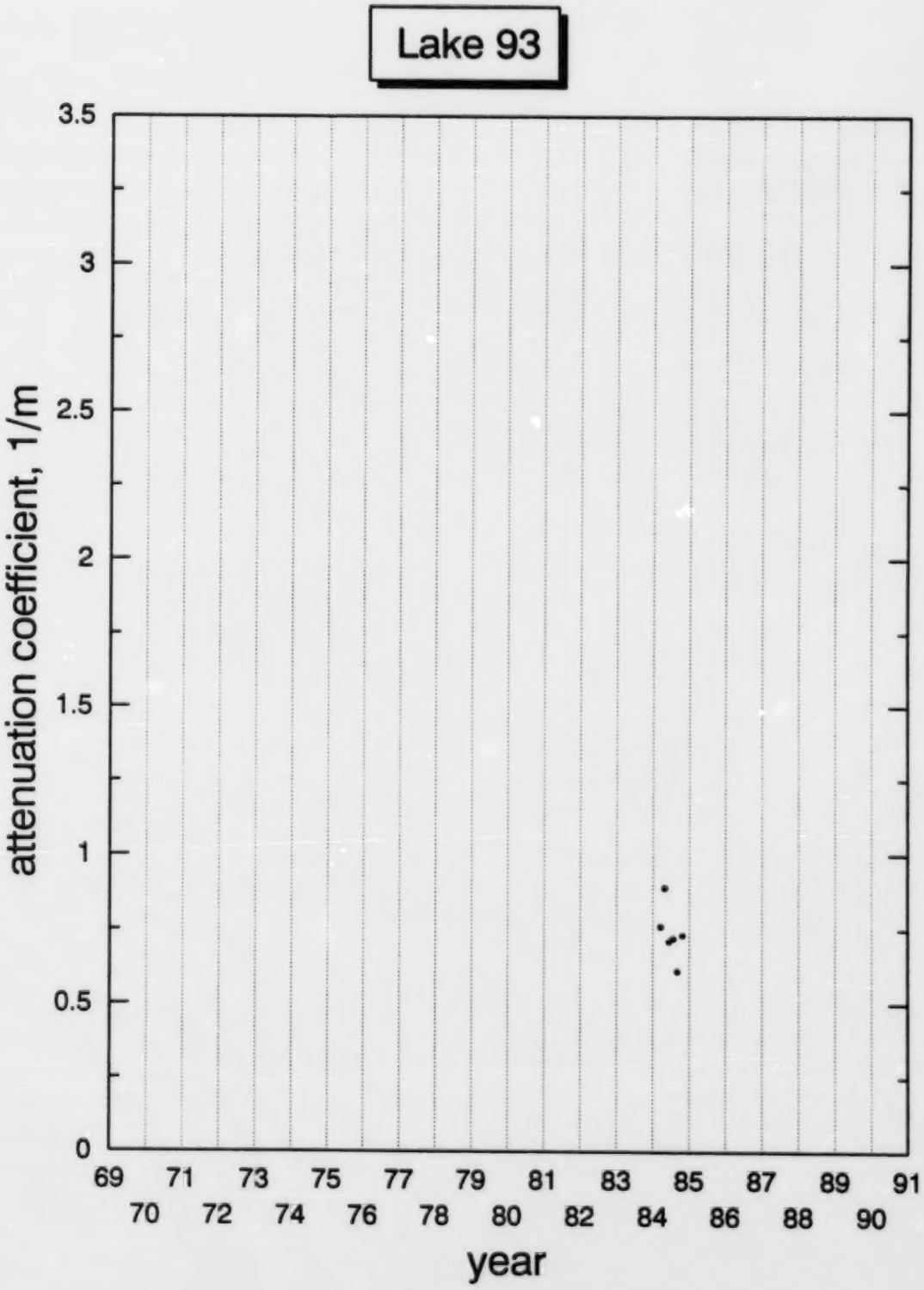
Table 3. Coefficients of variation (100×standard deviation/mean) of vertical attenuation coefficients for each lake (rows) and year (columns).

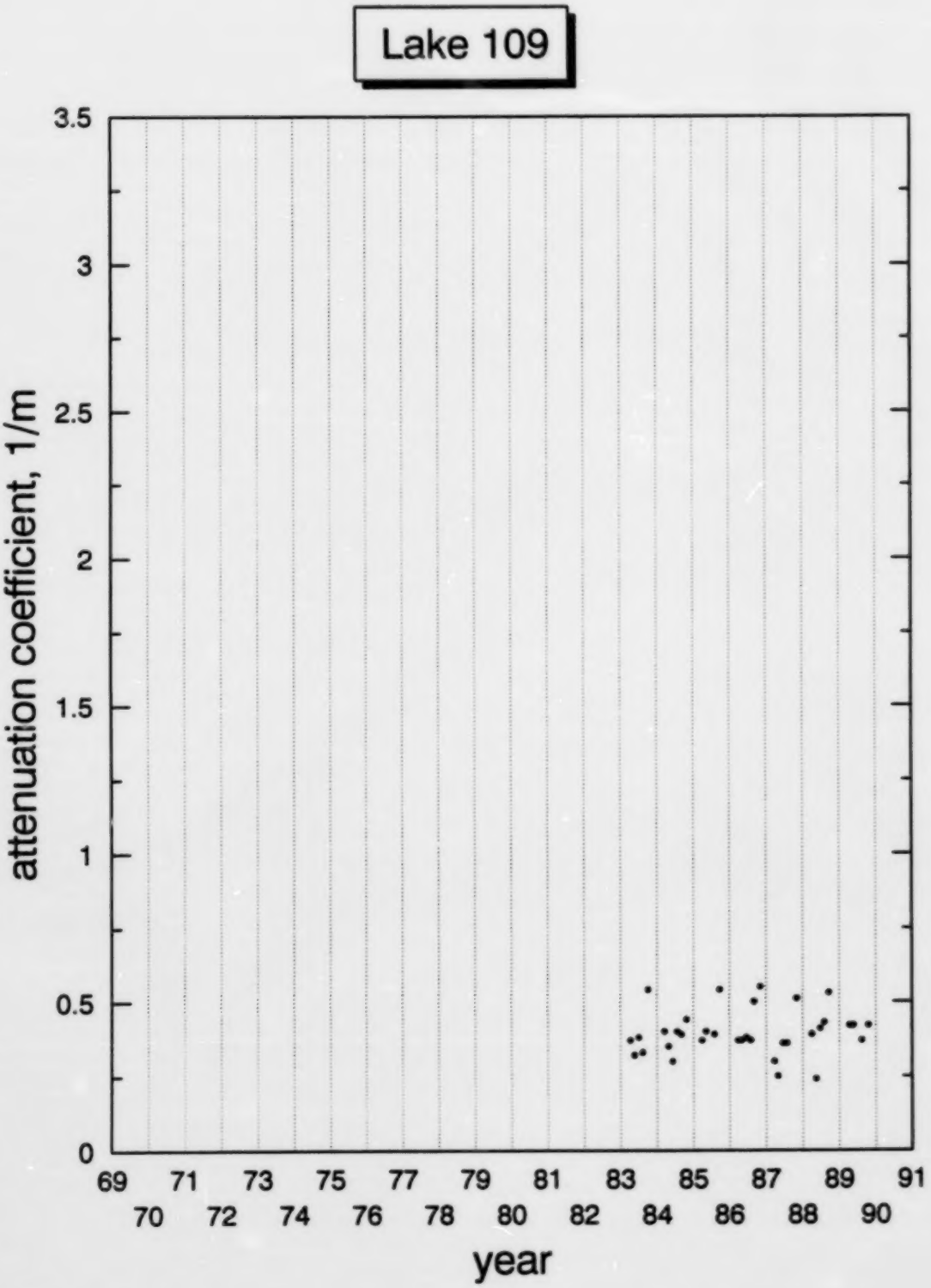
| | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 093 | | | | | | | | | | | | | | | | 12 | | | | | | |
| 099 | | | | | | | | | | | | | | | | | | | | | | |
| 103 | | | | | 15 | | | | | | | | | | | | | | | | | |
| 109 | | | | | | | | | | | | | | | 23 | 13 | 18 | 19 | 27 | 26 | 6 | |
| 110 | | | | | | | | | | | | | | | 20 | 12 | 4 | 12 | | | | |
| 111 | | | | | | | | | | | | | | | | 10 | | | | | | |
| 114 | | | 21 | | | 18 | 17 | | | 27 | 23 | 18 | 16 | 11 | 9 | 23 | 22 | 28 | 22 | 22 | | |
| 120 | | | 5 | 18 | | 9 | | | | | | | | | | | | | | | | |
| 127 | | | | | | | | | | 12 | | | | | | | | | | | | |
| 129 | | | 3 | 43 | | | | | | 9 | | | | | | | | | | | | |
| 130 | | | | | | | | | | 16 | | | | | | | | | | | | |
| 132 | | | | | | | | | | 5 | | | | | | | | | | | | |
| 149 | | | | | | | | | | | | | | | | | | | 19 | 25 | 32 | 20 |
| 161 | | | | | | | | | | | | | | | | | | | | | | |
| 164 | | | | | | | | | | | | | | | | | | | 6 | 21 | 19 | 18 |
| 165 | | | | | | | | | | | | | | | | | | | 49 | 18 | 22 | 19 |
| 221 | | | | | | | | | 17 | | | | | | | | 15 | 4 | 8 | 18 | 10 | 20 |
| 222 | | | | | | | | | 22 | | | 19 | 9 | 13 | 10 | 12 | 20 | 20 | 6 | 16 | 8 | 31 |
| 223 | | | | | | 11 | 15 | 13 | 17 | 19 | 32 | 25 | 23 | 26 | 14 | 43 | 12 | 18 | 22 | 25 | 21 | 18 |
| 224 | | | | | | 10 | 17 | 13 | 14 | | | | 12 | 10 | 9 | 19 | 14 | 27 | 14 | 16 | 8 | 20 |
| 225 | | | | | | | | | | | | | | | | 17 | 9 | 10 | 12 | | | |
| 226N | | | 12 | | 35 | 35 | 23 | 15 | 19 | 43 | 19 | 19 | 11 | 12 | 17 | 17 | 10 | 10 | 12 | 10 | 23 | 13 |
| 226S | | | | | 23 | 16 | 15 | 12 | 17 | 14 | 24 | 11 | 11 | 11 | 18 | 14 | 10 | 12 | 12 | 18 | 18 | 18 |
| 227 | 37 | 18 | 18 | 35 | 44 | 19 | 22 | 12 | 24 | 22 | 24 | 18 | 19 | 39 | 31 | 30 | 13 | 13 | 30 | 16 | 33 | 43 |
| 228 | | | 19 | | | | | | | | | | | | | | | | | | | |
| 230 | 12 | | 10 | 22 | | | 13 | 17 | | | | | | | | | | | | | | |
| 239 | 9 | 10 | 11 | 10 | 15 | 10 | 7 | 8 | 11 | 14 | 15 | 8 | 16 | 9 | 9 | 8 | 10 | 12 | 18 | 15 | 13 | 12 |
| 240 | 18 | 25 | 12 | 26 | | 7 | 9 | | 10 | | | | | | 9 | 22 | 16 | 18 | 15 | 14 | 15 | 7 |
| 241 | 16 | | 39 | | | | | | | | | | | | | | | | | | | |
| 260 | | | | | | | | | | | | | | | | | 18 | 8 | | | | |
| 261 | | | 30 | 28 | 17 | 17 | 9 | 10 | 10 | | | | | | | | | | | | | |
| 262 | | | | | | | | | | | | | | | | | | | 22 | | | |
| 265 | | | 16 | | | | | | | | | | | | | | | | | | | |
| 302N | | | 12 | 19 | 24 | 21 | 14 | 15 | | 17 | | 22 | 15 | 14 | 11 | 14 | 19 | 18 | 18 | 24 | 26 | 30 |
| 302S | | | | 20 | 20 | 11 | 12 | 13 | | 8 | | 33 | 14 | 9 | 16 | 16 | 18 | 20 | 29 | 31 | 27 | 25 |
| 303 | 51 | 26 | 23 | | | 21 | 22 | 24 | | | | | | 20 | | 64 | 21 | 31 | | | | |
| 304 | 18 | 18 | 15 | 42 | 17 | 15 | 18 | 21 | 17 | | | 8 | | 13 | | 30 | 12 | 16 | 13 | 12 | 17 | |
| 305 | 14 | | 15 | | | 12 | | | | | | | | 5 | 13 | 5 | 13 | 19 | | | | |
| 310 | | | | | | | | | | | | | | | | | | | | | | |
| 373 | | | | | | | | | | | | | | | 18 | 14 | 12 | 6 | 16 | 14 | 14 | 20 |
| 374 | | | | | | | | | | | | | | | 11 | 14 | | 12 | 13 | 17 | 17 | |
| 375 | | | | | | | | | | | | | | | 11 | | | 5 | 6 | 11 | 15 | 10 |
| 377 | | | | | | | | | | | | | | | | | | | 10 | 24 | 20 | 12 |
| 382 | | | | | | | | | 8 | 10 | 13 | 13 | | 2 | 8 | 11 | 9 | 11 | 11 | 16 | 8 | 10 |
| 382B | | | | | | | | | | 21 | 21 | 13 | | 12 | 11 | 13 | | | | | | |
| 383 | | | | | | 6 | 11 | | | 11 | 15 | | | | | | | | | | | |
| 384 | | | | | | | | | | 12 | | | | | | | | | | | | |
| 442 | | | | | | | | | | | | | | | | | | | 16 | 15 | 23 | 19 |
| 622 | | | | | | | | | | | | | | | 11 | | | | | | | |
| 623 | | | | | | | | | | | | | | | 12 | 8 | 9 | | | | | |
| 629 | | | | | | | | | | | | | | | 15 | 10 | | | | | | |
| 661 | | | | | | | | | | | | | | 19 | | | | | | | | |
| 938 | | | | | | | | | | | | | | | | | | | 28 | 13 | 19 | 19 |

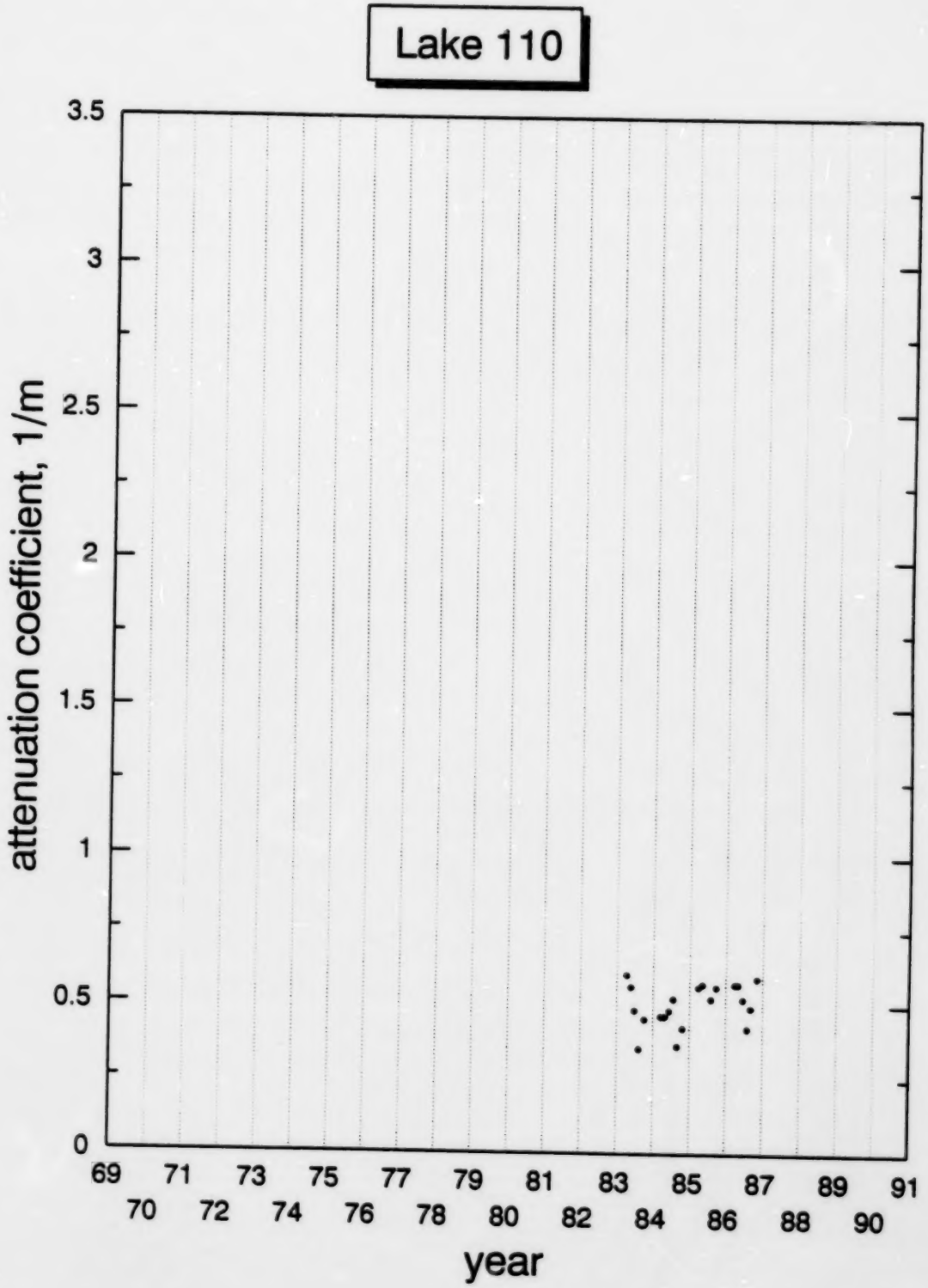
Table 4. Total number of light profiles measured in each lake (rows) and year (columns).

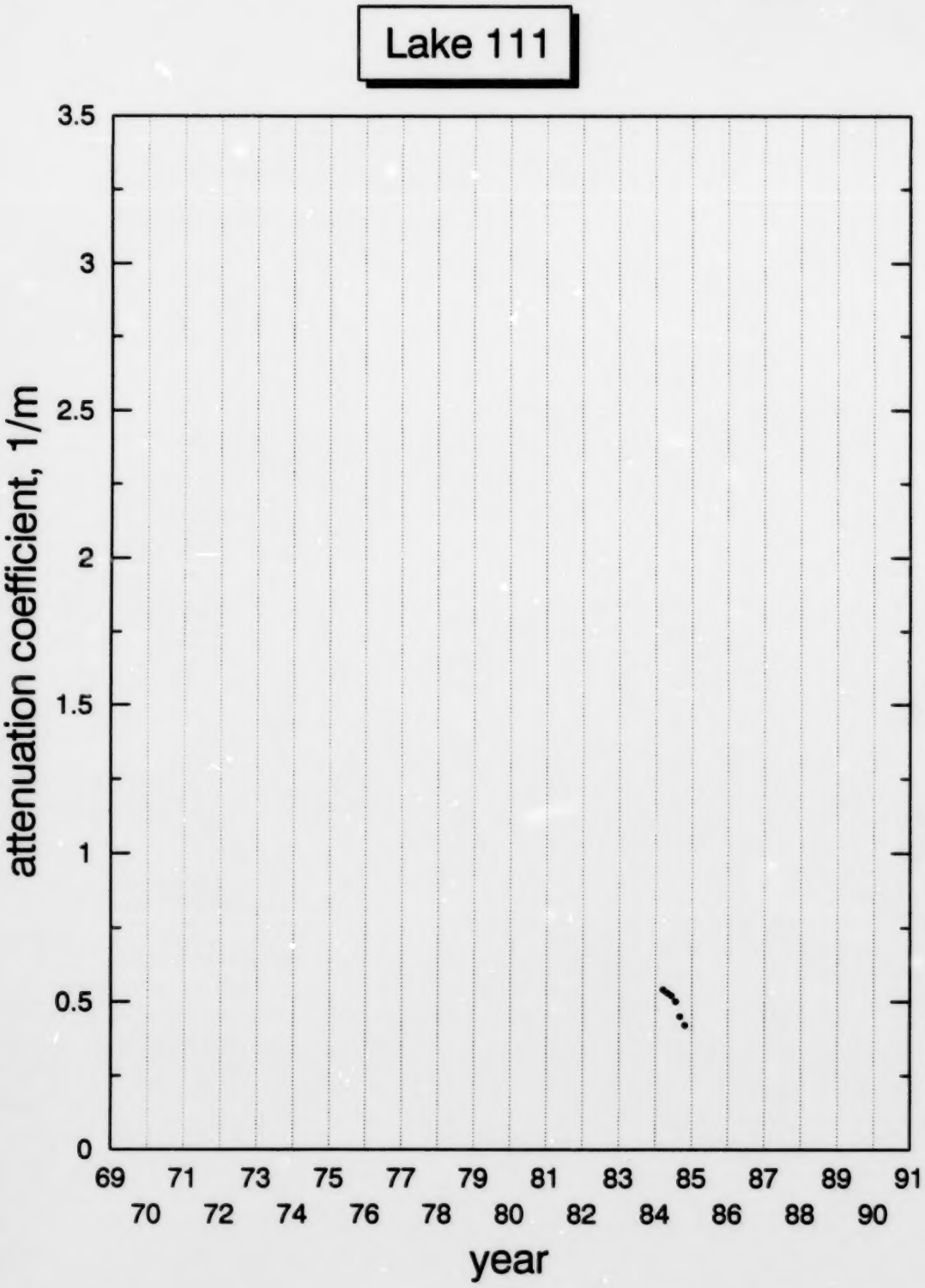
| | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 093 | | | | | | | | | | | | | | | | 6 | | | | | | |
| 099 | 1 | | | | | | | | | | | | | | | | | | | | | |
| 103 | | | | | 3 | | | | | | | | | | | | | | | | | |
| 109 | | | | | | | | | | | | | | | 5 | 6 | 4 | 6 | 5 | 5 | 4 | |
| 110 | | | | | | | | | | | | | | | 5 | 6 | 4 | 6 | | | | |
| 111 | | | | | | | | | | | | | | | | 6 | | | | | | |
| 114 | 1 | | 4 | | | 11 | 15 | | | 9 | 13 | 13 | 12 | 12 | 11 | 14 | 12 | 14 | 11 | 6 | | |
| 120 | 1 | | 5 | 7 | | 10 | | | | | | | | | | | | | | | | |
| 127 | | | | | | | | | | 8 | | | | | | | | | | | | |
| 129 | | | 3 | 7 | | | | | | 8 | | | | | | | | | | | | |
| 130 | | | | | | | | | | 8 | | | | | | | | | | | | |
| 132 | | | | | | | | | | 9 | | | | | | | | | | | | |
| 149 | | | | | | | | | | | | | | | | | | | 4 | 8 | 5 | 11 |
| 161 | 1 | | | | | | | | | | | | | | | | | | | | | |
| 164 | | | | | | | | | | | | | | | | | | | 5 | 10 | 4 | 11 |
| 165 | | | | | | | | | | | | | | | | | | | 5 | 10 | 6 | 11 |
| 221 | | | | | | | | | 6 | | | | | | | | 5 | 2 | 10 | 6 | 6 | 12 |
| 222 | | | | | | | | | 6 | | | 6 | 9 | 7 | 6 | 6 | 7 | 7 | 7 | 6 | 6 | 12 |
| 223 | | | | | | 11 | 13 | 12 | 13 | 9 | 14 | 13 | 15 | 14 | 13 | 16 | 14 | 12 | 13 | 12 | 9 | 12 |
| 224 | | | | | | 11 | 11 | 13 | 9 | | | | 13 | 7 | 8 | 8 | 8 | 7 | 7 | 6 | 6 | 12 |
| 225 | | | | | | | | | | | | | | | | 4 | 5 | 5 | 19 | | | |
| 226N | | | 4 | | 30 | 13 | 15 | 22 | 13 | 17 | 12 | 12 | 13 | 7 | 7 | 7 | 8 | 9 | 7 | 6 | 5 | 12 |
| 226S | | | | | 28 | 13 | 15 | 23 | 13 | 14 | 13 | 13 | 14 | 8 | 7 | 6 | 8 | 9 | 7 | 6 | 6 | 11 |
| 227 | 5 | 23 | 14 | 15 | 30 | 12 | 14 | 15 | 13 | 10 | 13 | 14 | 14 | 14 | 16 | 13 | 14 | 15 | 13 | 13 | 10 | 12 |
| 228 | | | 3 | 1 | | | | | | | | | | | | | | | | | | |
| 230 | 2 | | 6 | 7 | | | 20 | 11 | | | | | | | | | | | | | | |
| 239 | 7 | 16 | 6 | 8 | 28 | 12 | 11 | 15 | 10 | 10 | 17 | 18 | 15 | 14 | 14 | 14 | 14 | 13 | 16 | 51 | 34 | 22 |
| 240 | 3 | 17 | 6 | 7 | | 13 | 15 | | 9 | | | | | | 9 | 7 | 8 | 5 | 6 | 11 | 18 | 11 |
| 241 | 2 | | 6 | | | | | | | | | | | | | | | | | | | |
| 260 | | | | | | | | | | | | | | | | | 3 | 6 | | | | |
| 261 | | | 6 | 7 | 13 | 13 | 14 | 13 | 7 | | | | | | | | | | | | | |
| 262 | | | | | | | | | | | | | | | | | | | 5 | | | |
| 265 | | | 5 | | | | | | | | | | | | | | | | | | | |
| 302N | 1 | | 4 | 13 | 14 | 15 | 13 | 17 | | 11 | | 9 | 12 | 13 | 15 | 16 | 15 | 14 | 13 | 12 | 11 | 11 |
| 302S | | | | 11 | 14 | 14 | 13 | 18 | | 11 | | 10 | 12 | 15 | 15 | 15 | 14 | 14 | 13 | 12 | 11 | 11 |
| 303 | 2 | 8 | 8 | | | 7 | 15 | 12 | | | | | | 6 | | 5 | 7 | 5 | | | | |
| 304 | 3 | 9 | 16 | 14 | 13 | 10 | 15 | 14 | 7 | | | 4 | | 6 | | 6 | 7 | 6 | 7 | 4 | 4 | |
| 305 | 7 | | 5 | | | 12 | | | | | | | | 7 | 6 | 7 | 6 | 8 | | | | |
| 310 | 1 | | | | | | | | | | | | | | | | | | | | | |
| 373 | | | | | | | | | | | | | | | 6 | 6 | 5 | 6 | 9 | 11 | 7 | 11 |
| 374 | | | | | | | | | | | | | | | 5 | 6 | | 5 | 5 | 3 | 5 | |
| 375 | | | | | | | | | | | | | | | 5 | | | 5 | 5 | 4 | 4 | 11 |
| 377 | | | | | | | | | | | | | | | | | | | 4 | 9 | 8 | 11 |
| 382 | | | | | | | | | 7 | 10 | 12 | 6 | | 6 | 6 | 6 | 6 | 7 | 7 | 8 | 10 | 12 |
| 382B | | | | | | | | | | 9 | 12 | 7 | | 6 | 6 | 6 | | | | | | |
| 383 | | | | | | 14 | 17 | | | 9 | 12 | | | | | | | | | | | |
| 384 | | | | | | | | | | 8 | | | | | | | | | | | | |
| 442 | | | | | | | | | | | | | | | | | | | 4 | 11 | 6 | 11 |
| 622 | | | | | | | | | | | | | | | 5 | | | | | | | |
| 623 | | | | | | | | | | | | | | | 5 | 6 | 5 | | | | | |
| 629 | | | | | | | | | | | | | | | 5 | 6 | | | | | | |
| 661 | | | | | | | | | | | | | | 6 | | | | | | | | |
| 938 | | | | | | | | | | | | | | | | | | | 4 | 9 | 8 | 11 |

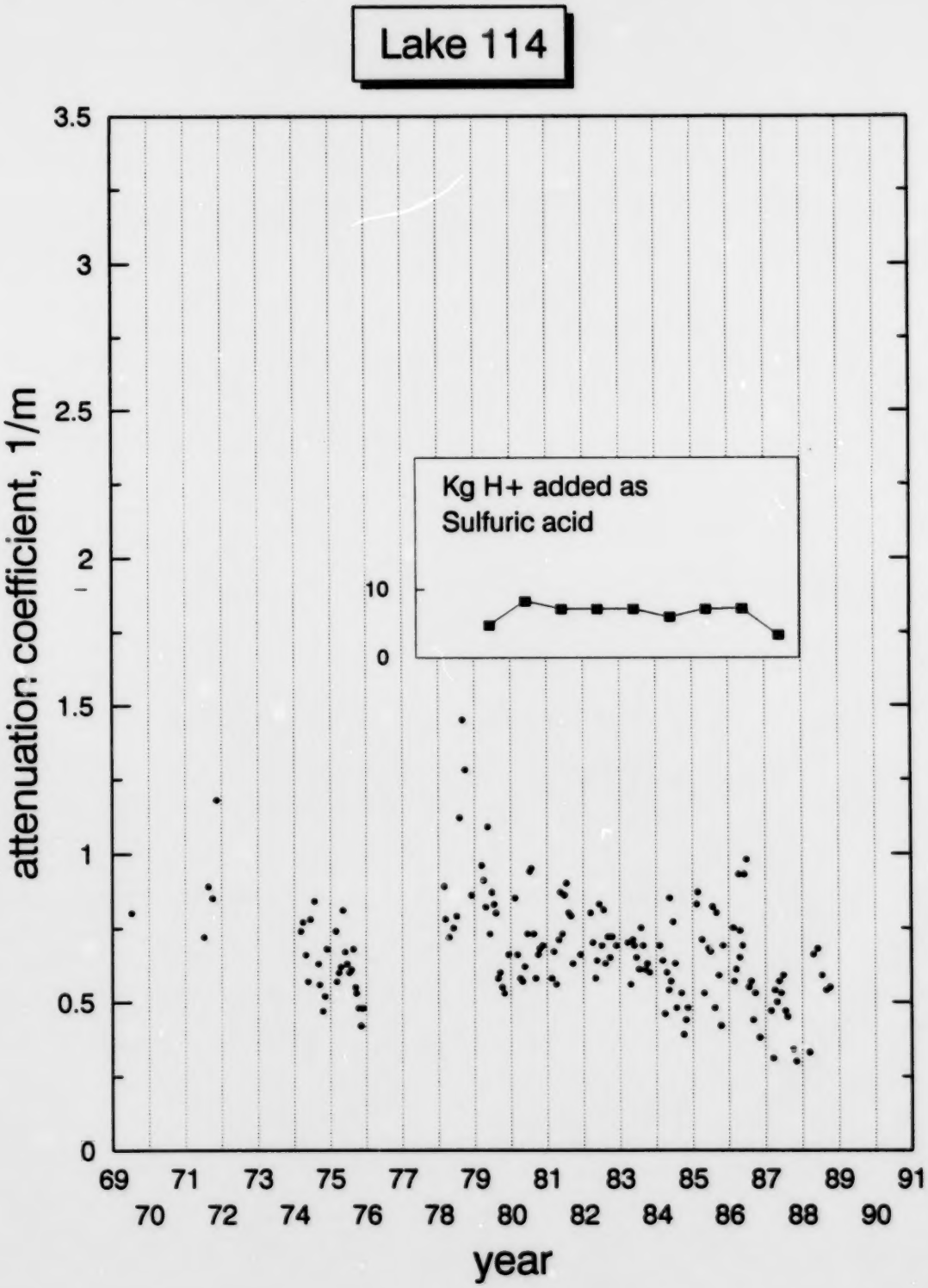
Appendix 1. Graphic presentation of mixed layer extinction coefficients for 49 ELA lakes sampled between 1969 and 1990. Because data were collected only during the ice-free season, the time axis within each year is expanded: the vertical line marking the start of the year is April 1, and the vertical line marking the end of the year is December 1. In order to facilitate intercomparisons between lakes, all data are graphed on a single set of scales, regardless of the quantity or range of information available for any particular lake. Whole-lake manipulations are indicated directly on the graphs; this facilitates interpretation of causal linkages between these manipulations and changes in transparency.

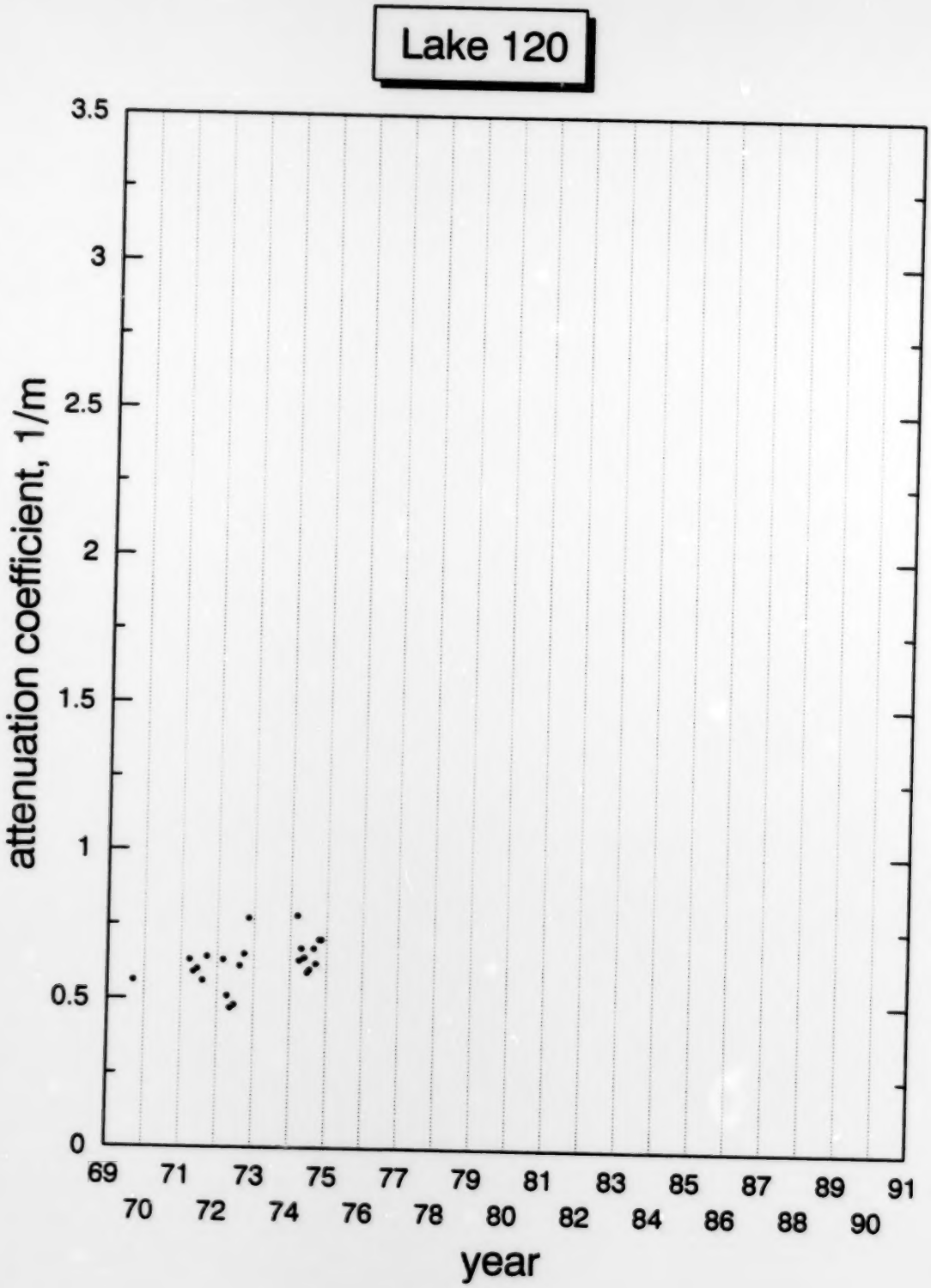

Lake 93
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year

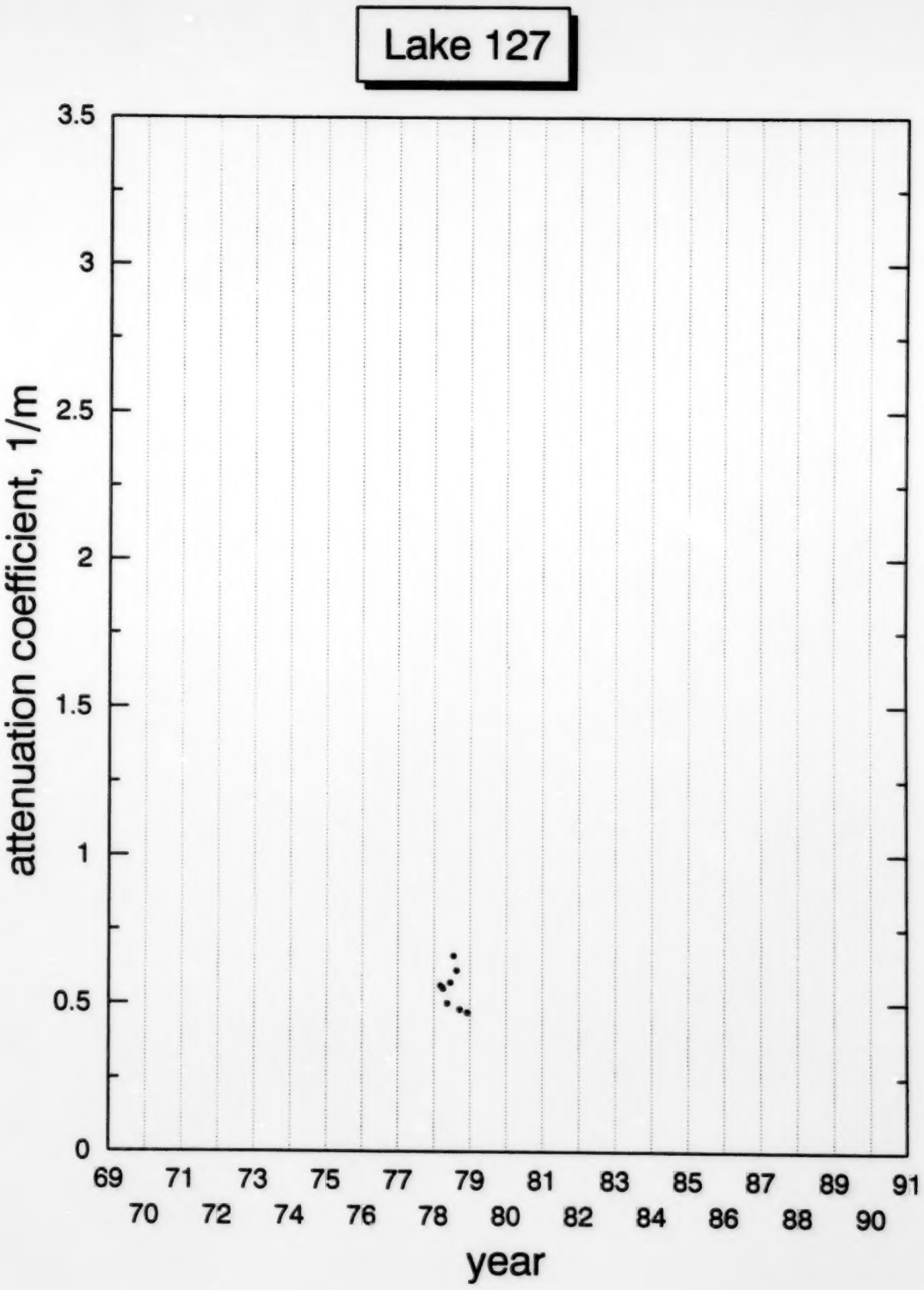

Lake 109
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69 71 73 75 77 79 81 83 85 87 89 91
70 72 74 76 78 80 82 84 86 88 90
year

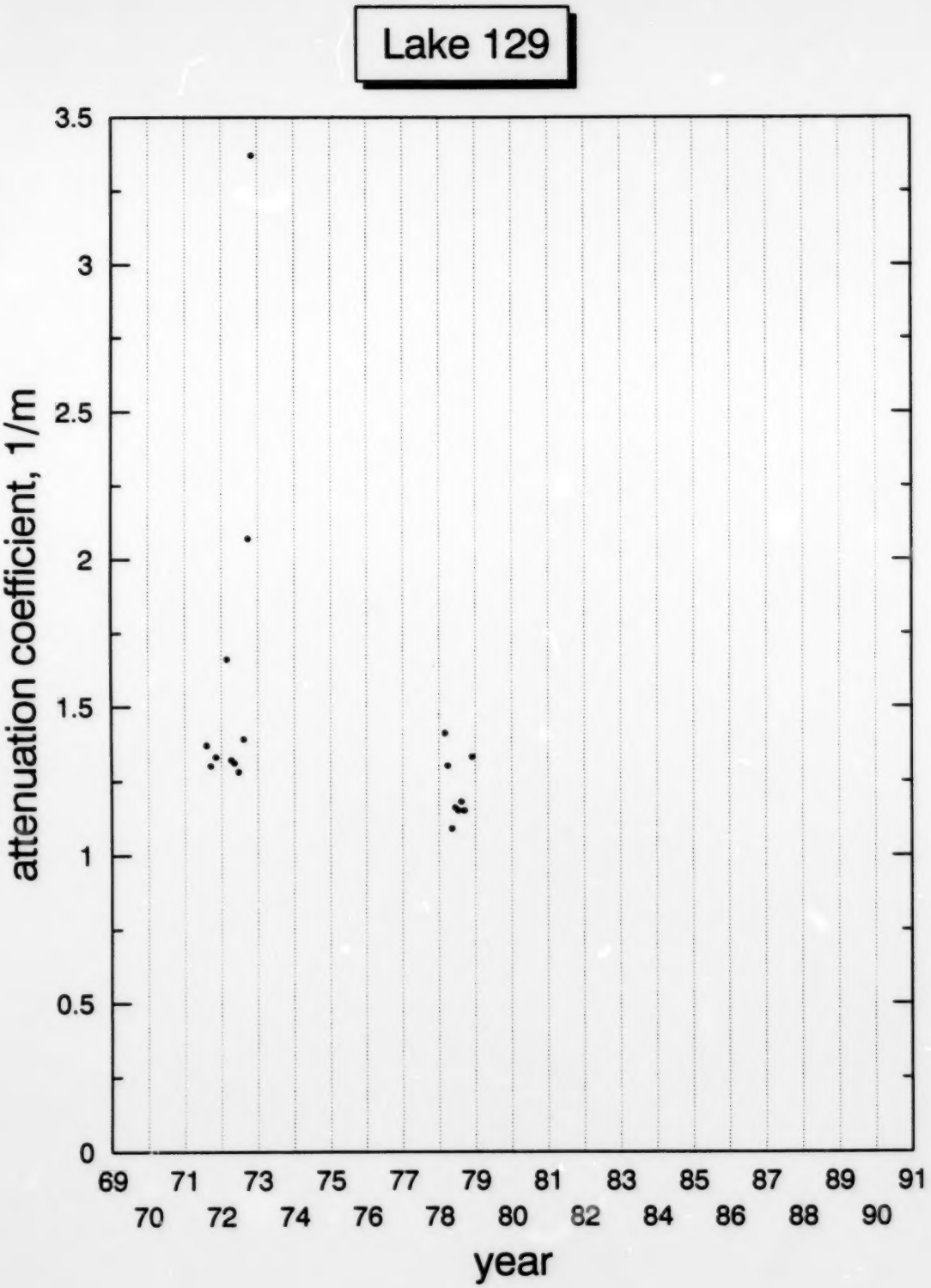

Lake 110
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69 71 73 75 77 79 81 83 85 87 89 91
70 72 74 76 78 80 82 84 86 88 90
year

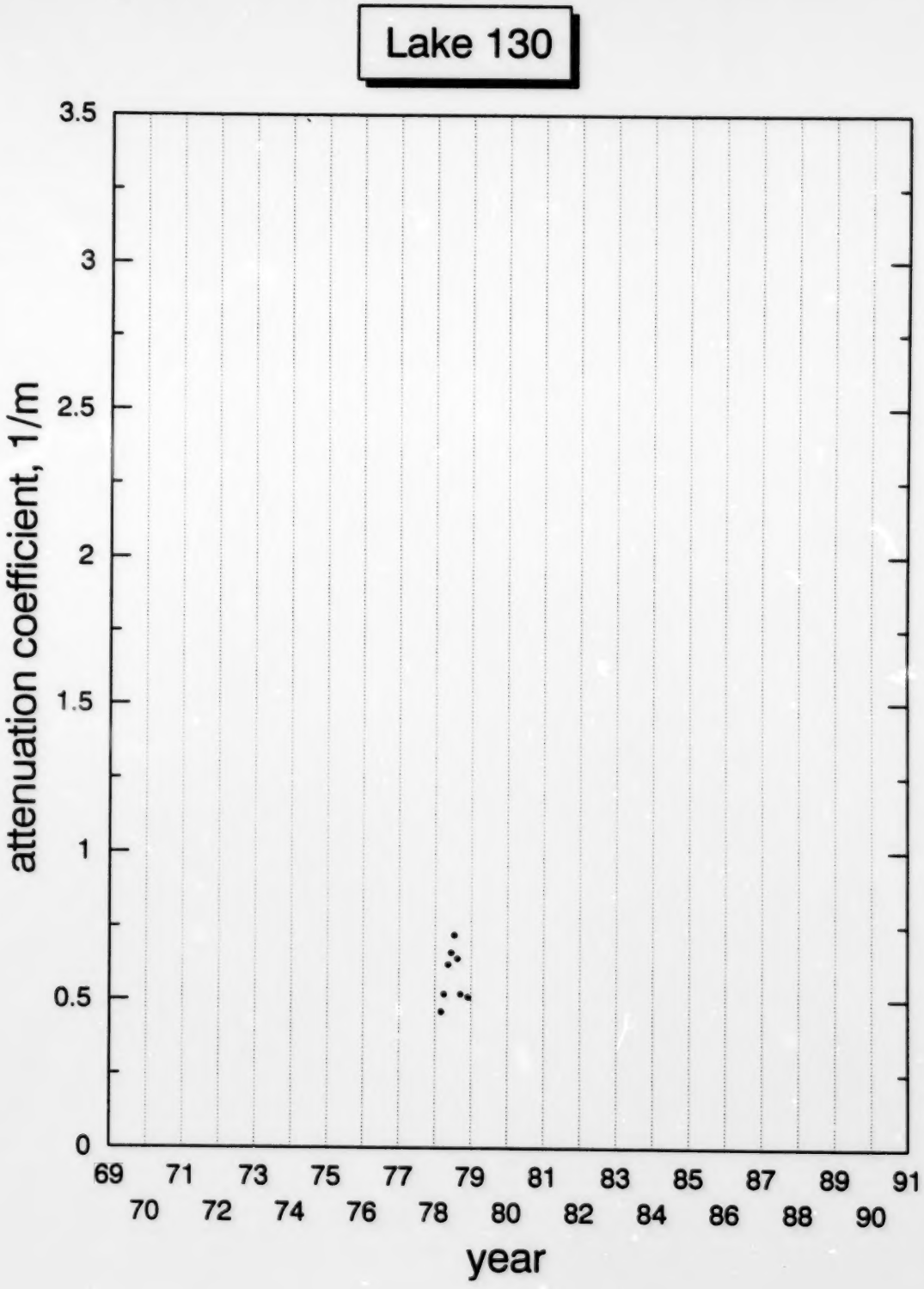

Lake 111
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69 71 73 75 77 79 81 83 85 87 89 91
70 72 74 76 78 80 82 84 86 88 90
year

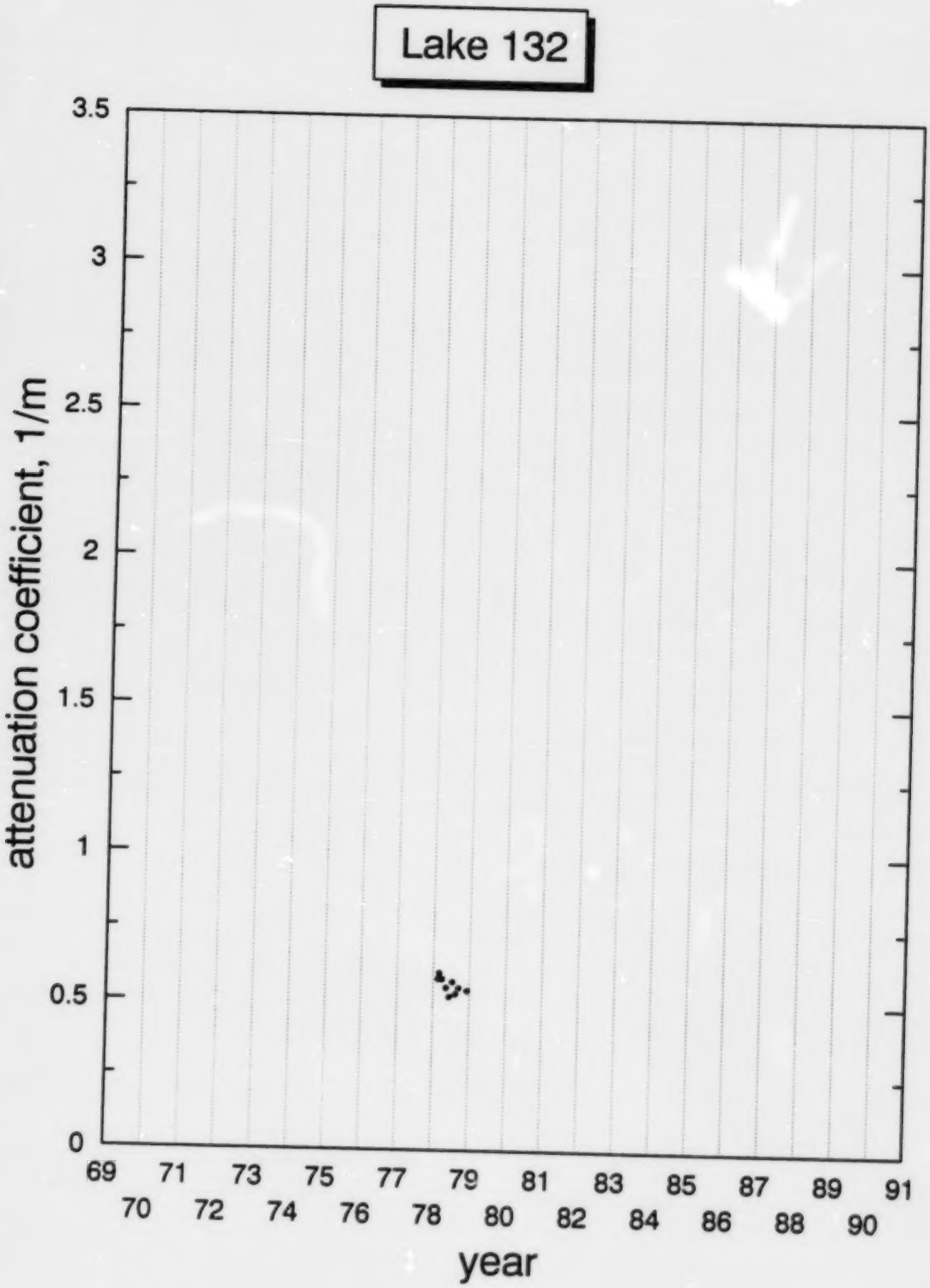

Lake 114
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
Kg H+ added as
Sulfuric acid
10
0
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year

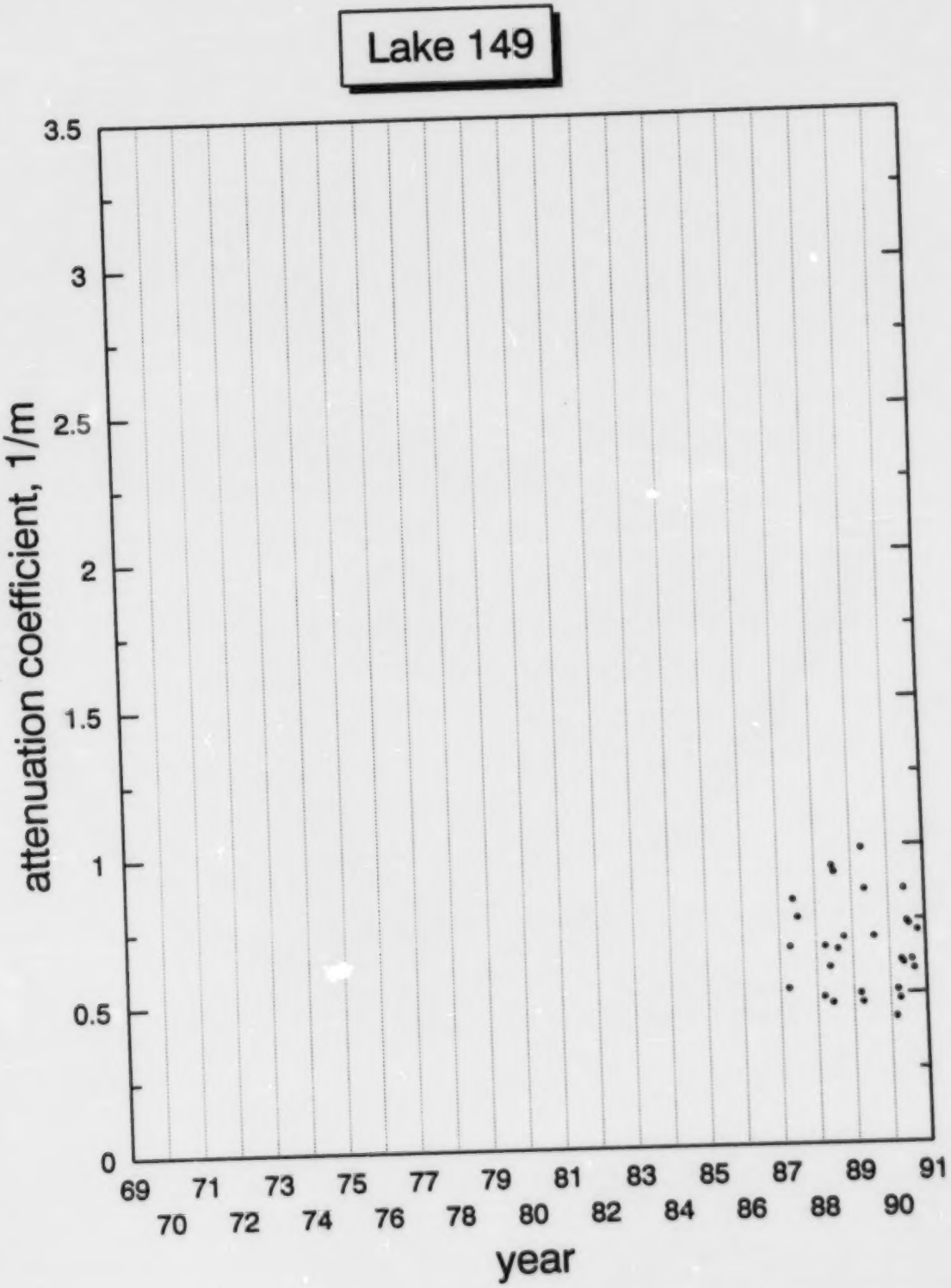

Lake 120
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year

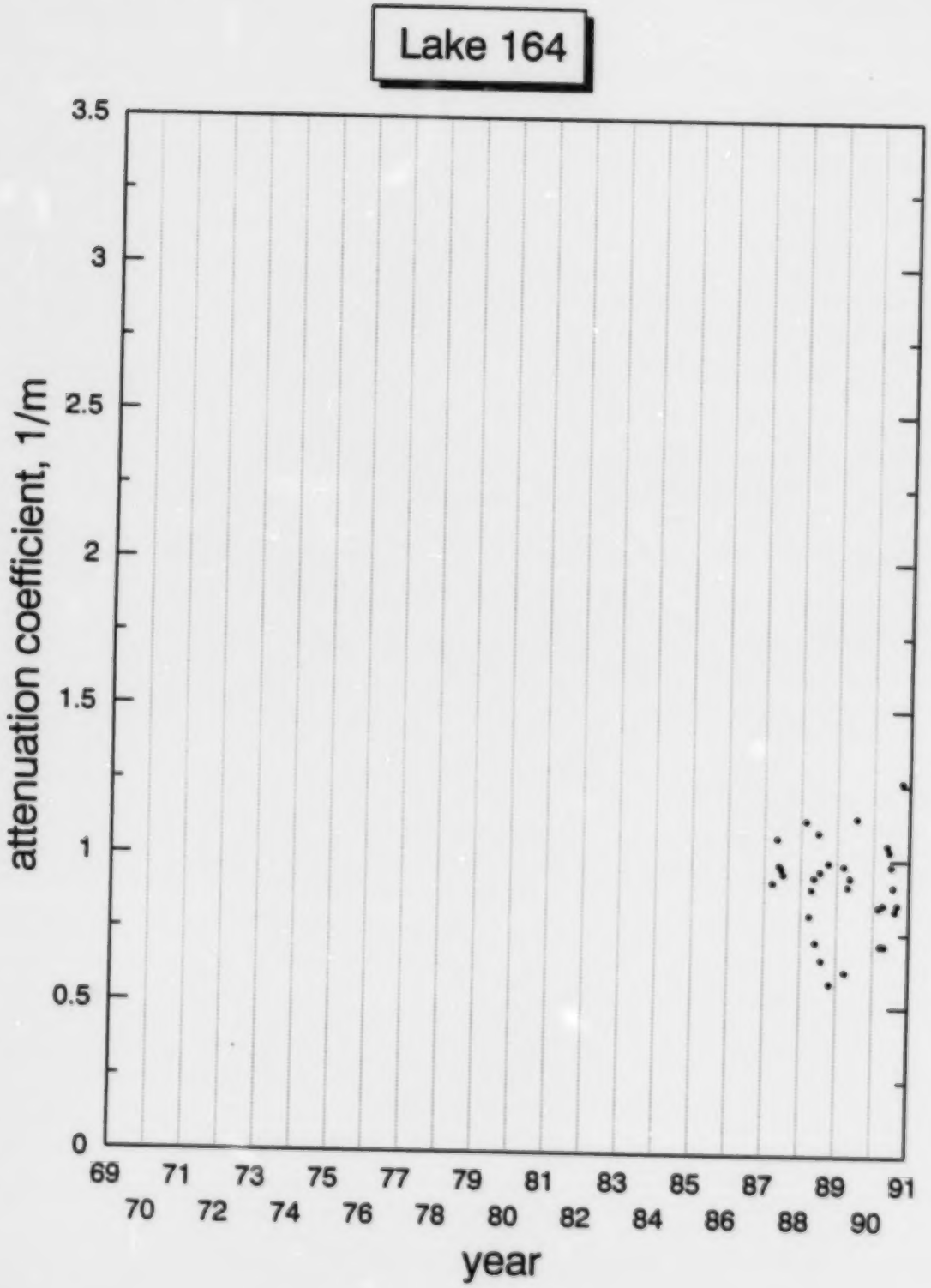

Lake 127
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69 71 73 75 77 79 81 83 85 87 89 91
70 72 74 76 78 80 82 84 86 88 90
year

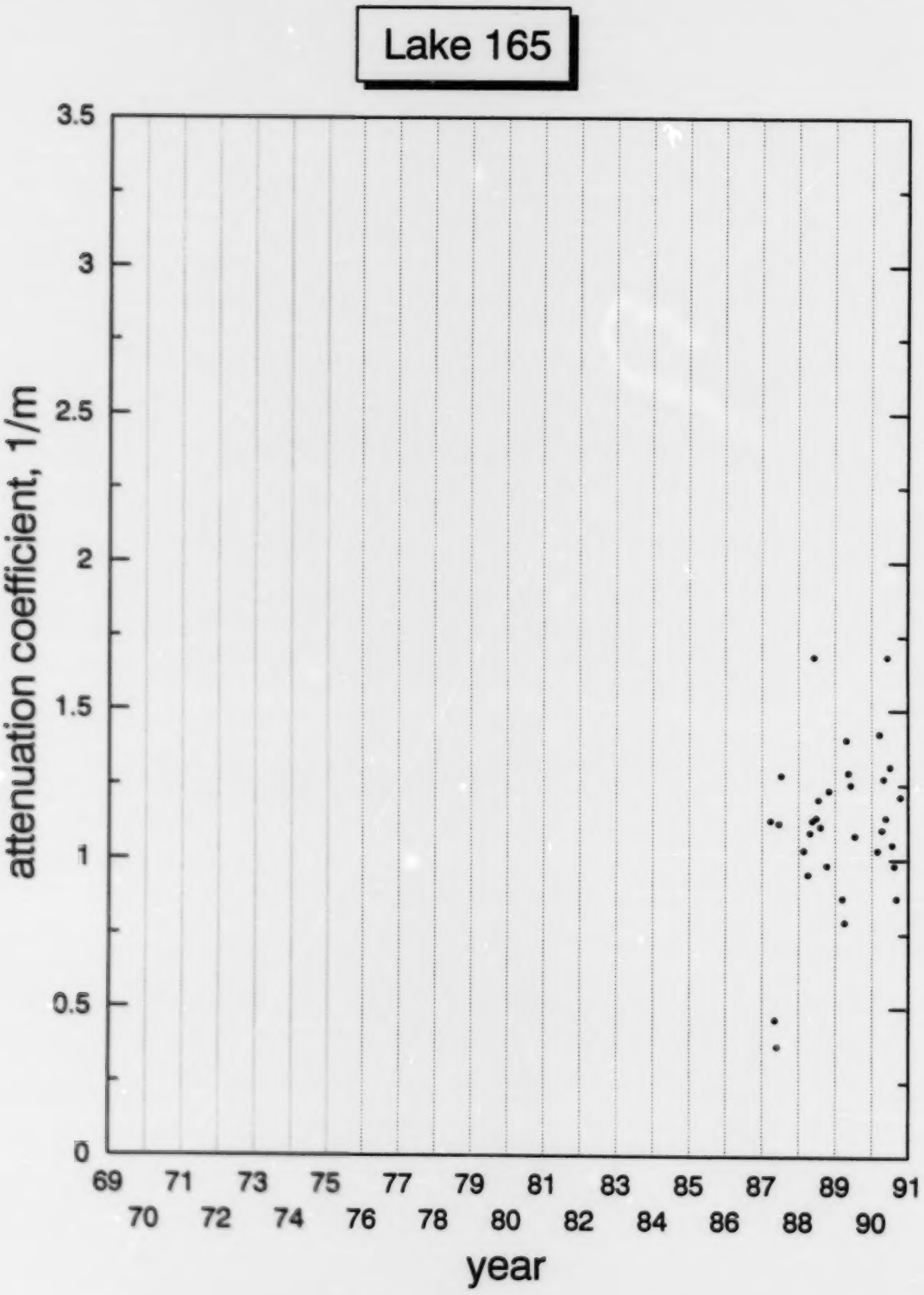

Lake 129
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year

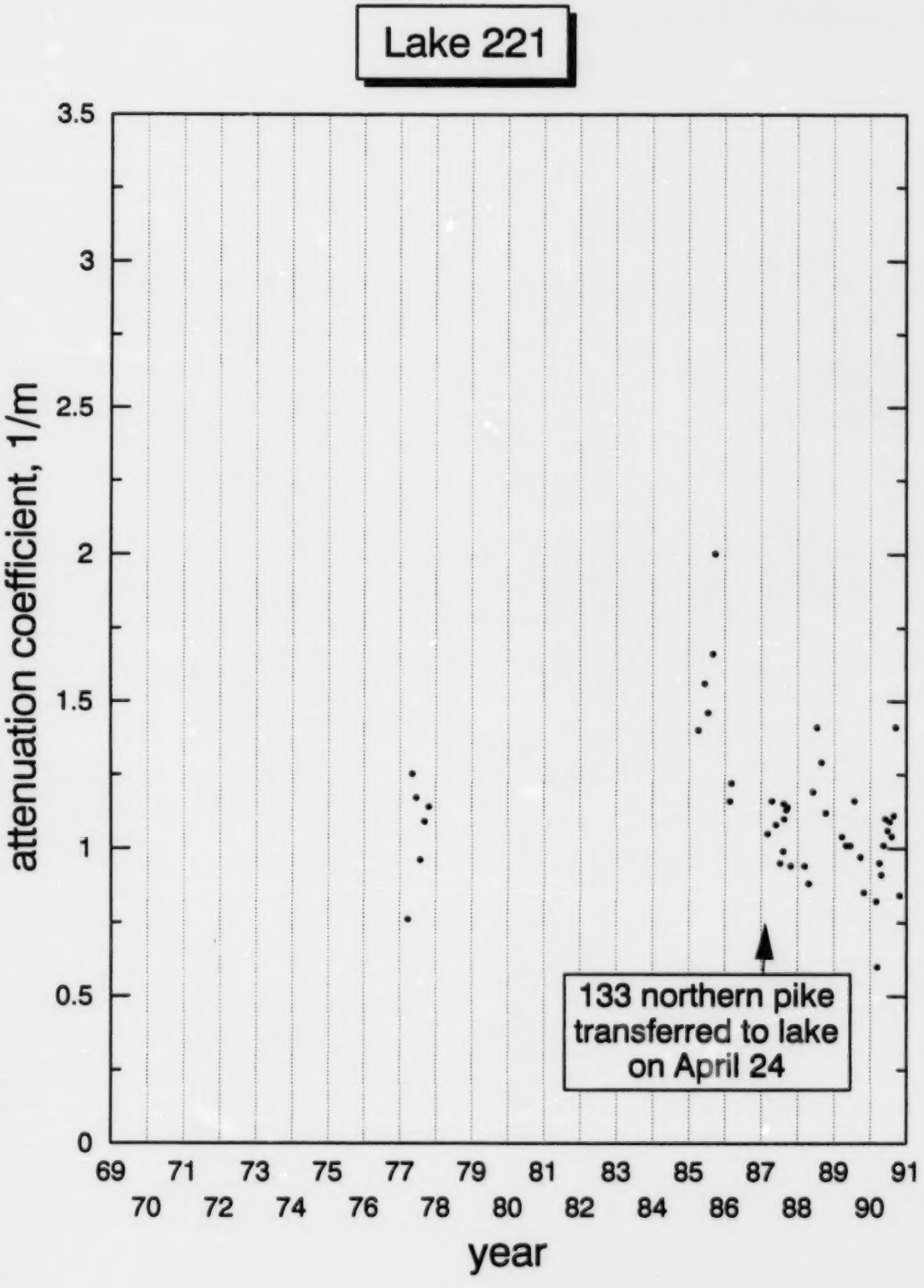

Lake 130
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69 71 73 75 77 79 81 83 85 87 89 91
70 72 74 76 78 80 82 84 86 88 90
year

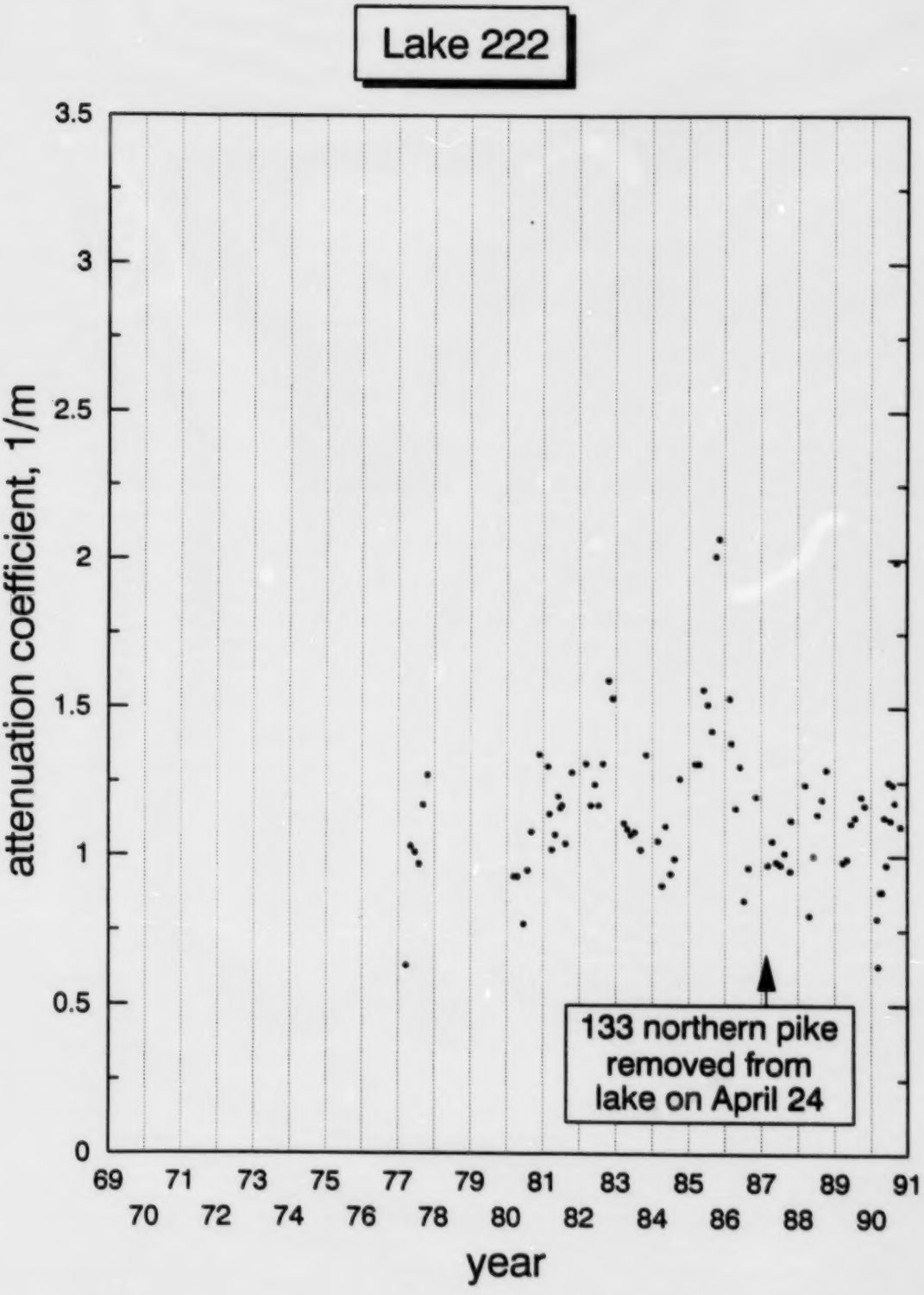

Lake 132
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year

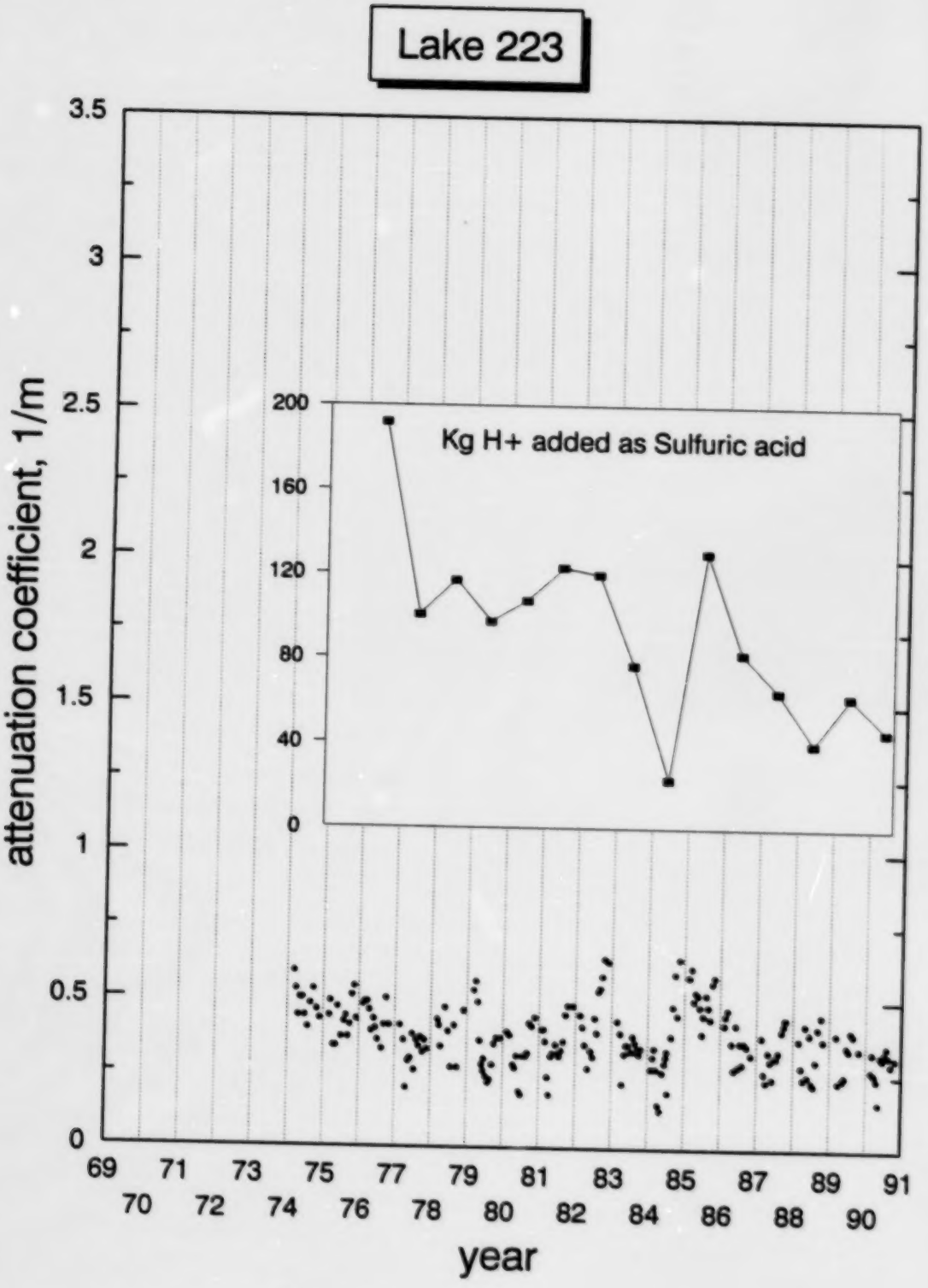

Lake 149
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year

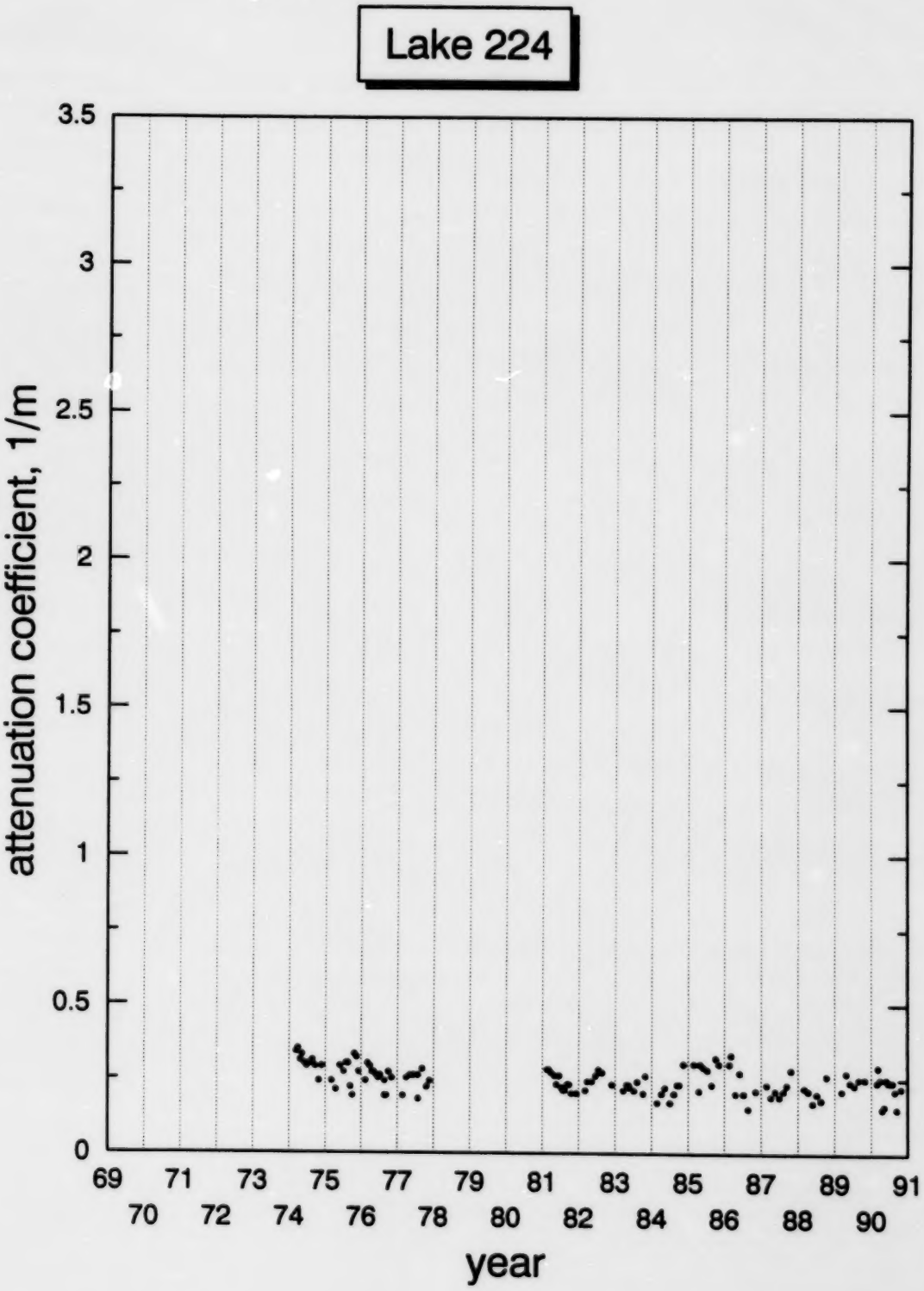

Lake 164
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year

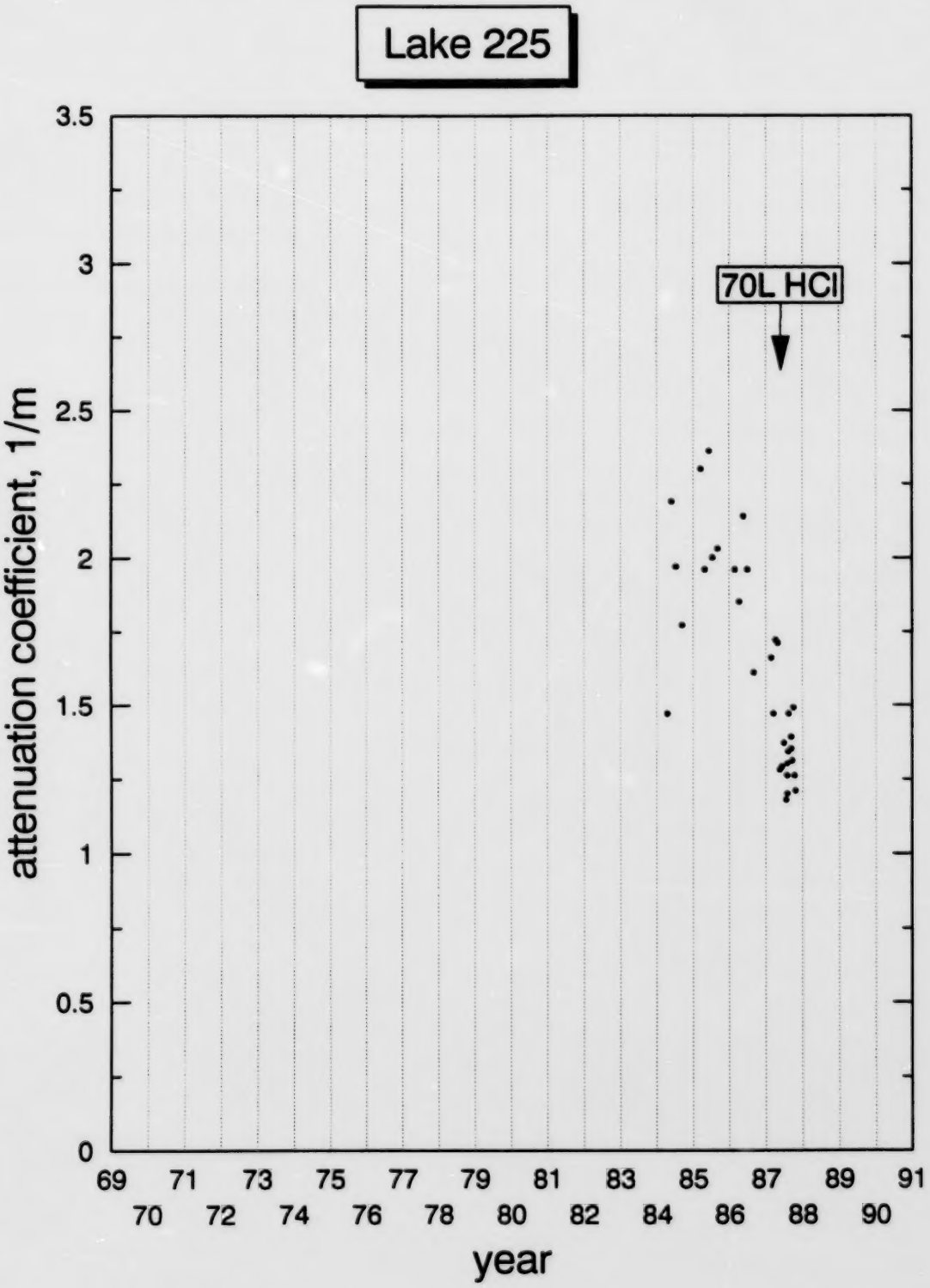

Lake 165
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year

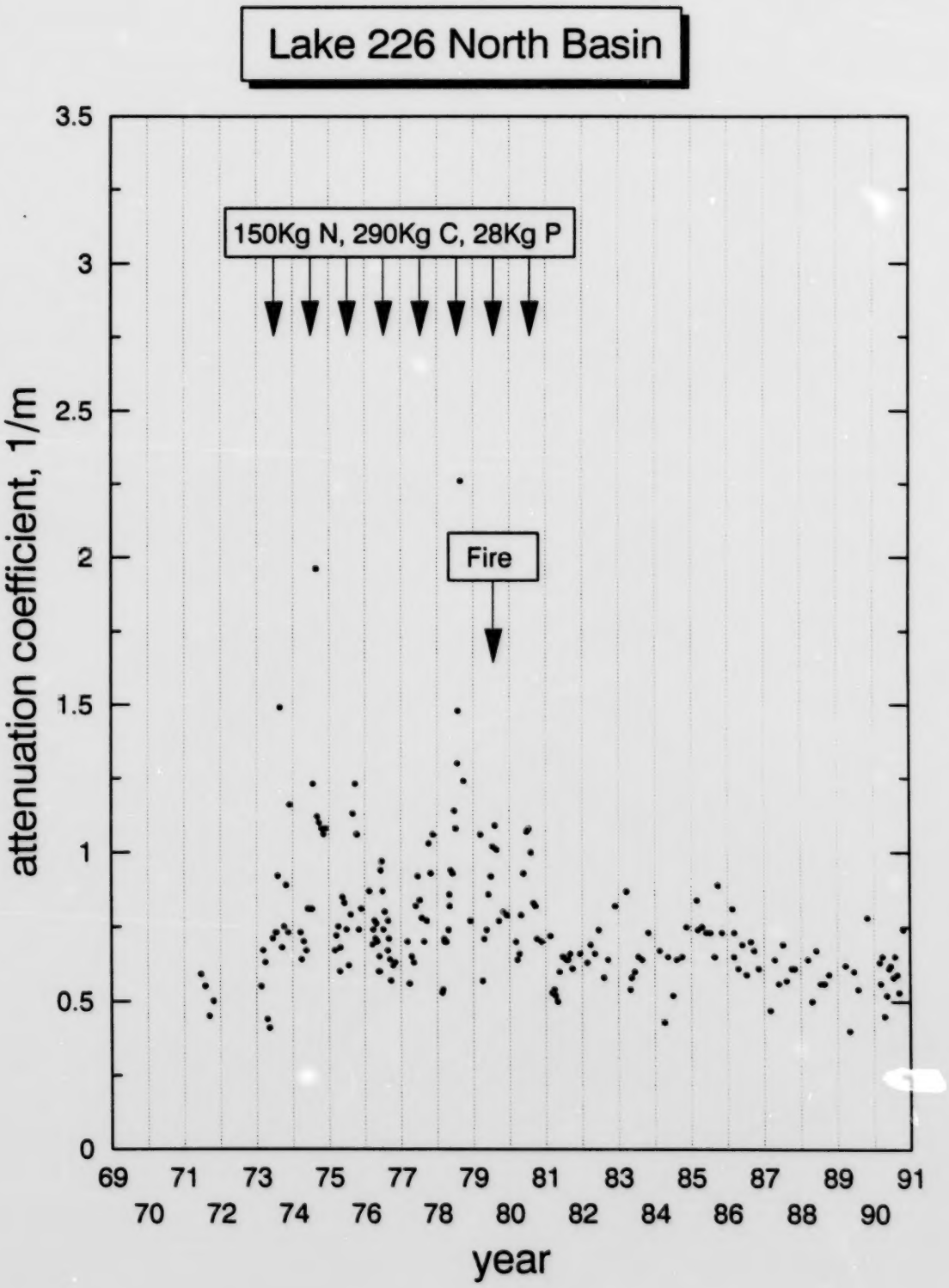

Lake 221
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year
133 northern pike transferred to lake on April 24

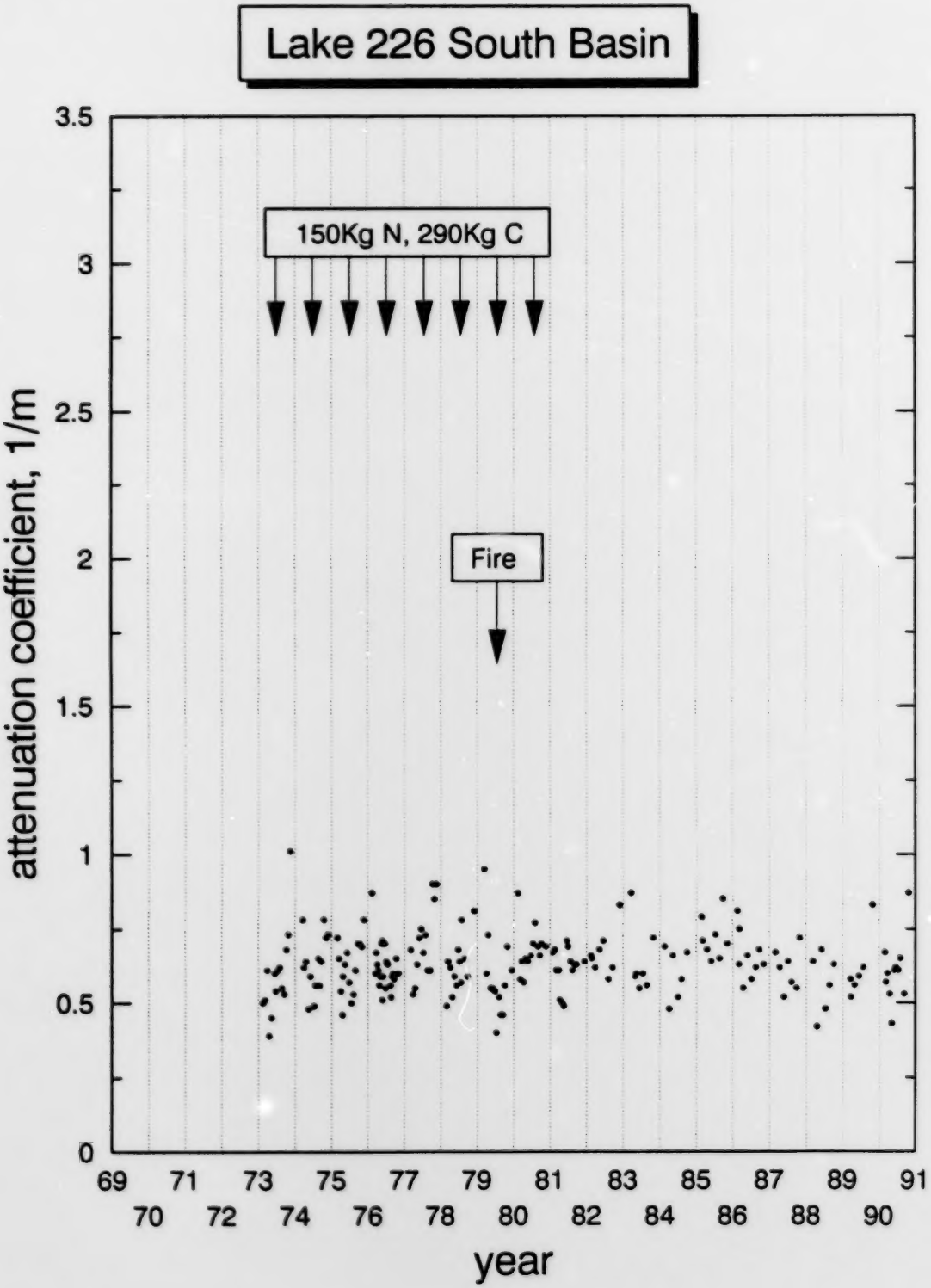

Lake 222
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69 71 73 75 77 79 81 83 85 87 89 91
70 72 74 76 78 80 82 84 86 88 90
year
133 northern pike removed from lake on April 24

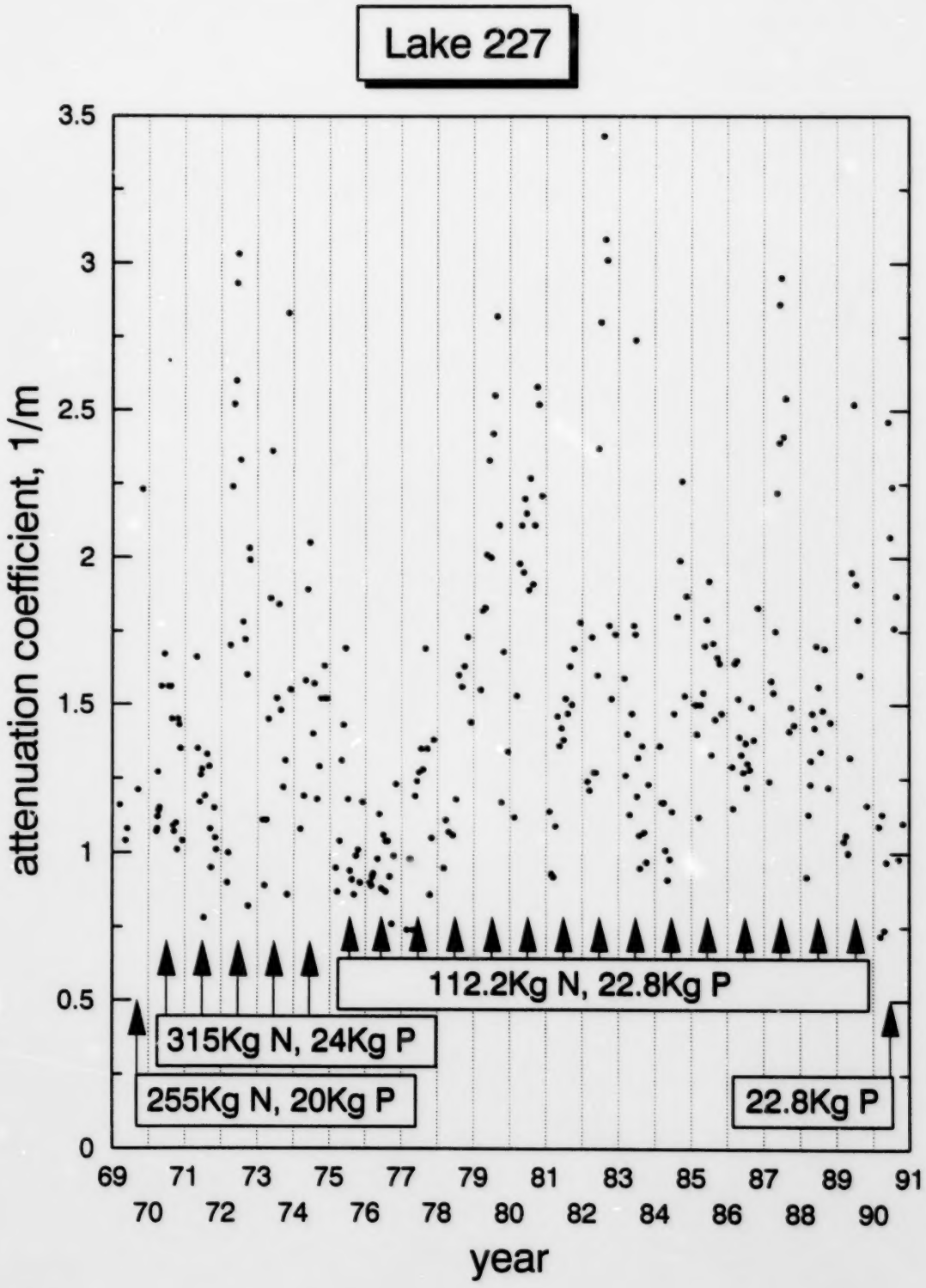

Lake 223
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
Kg H+ added as Sulfuric acid
200
160
120
80
40
0
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year

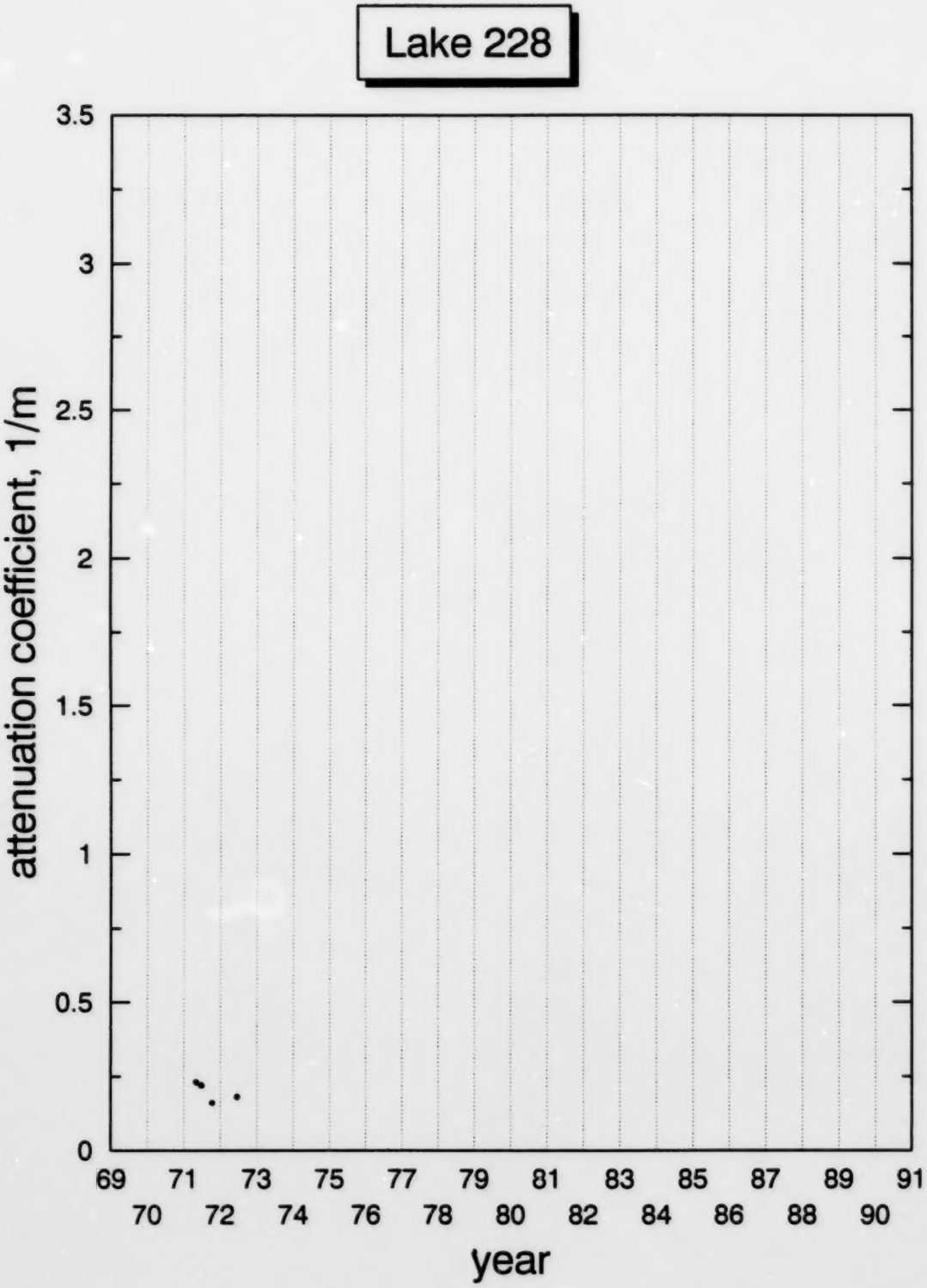

Lake 224
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69 71 73 75 77 79 81 83 85 87 89 91
70 72 74 76 78 80 82 84 86 88 90
year

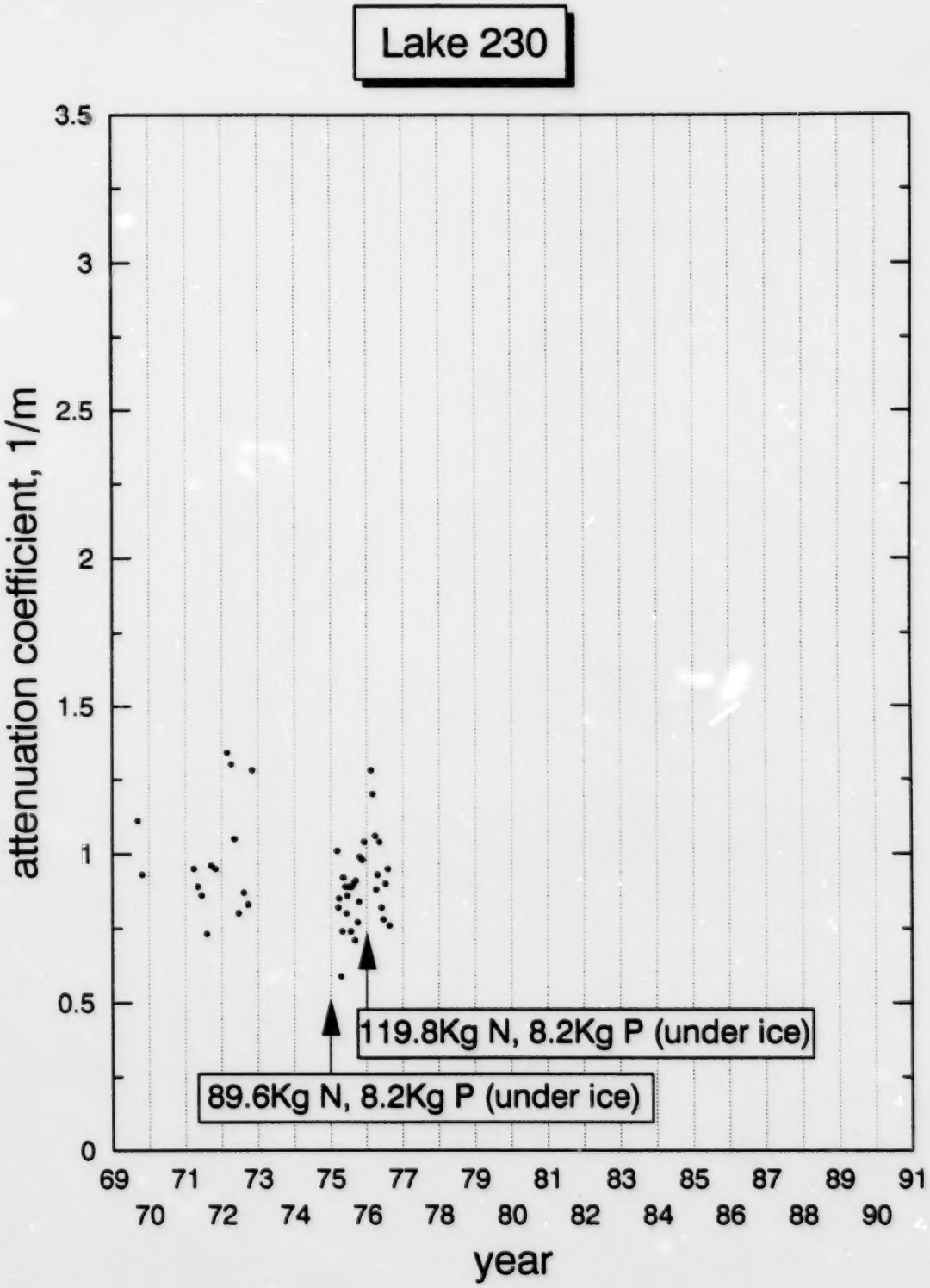

Lake 225
70L HCl
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69 71 73 75 77 79 81 83 85 87 89 91
70 72 74 76 78 80 82 84 86 88 90
year

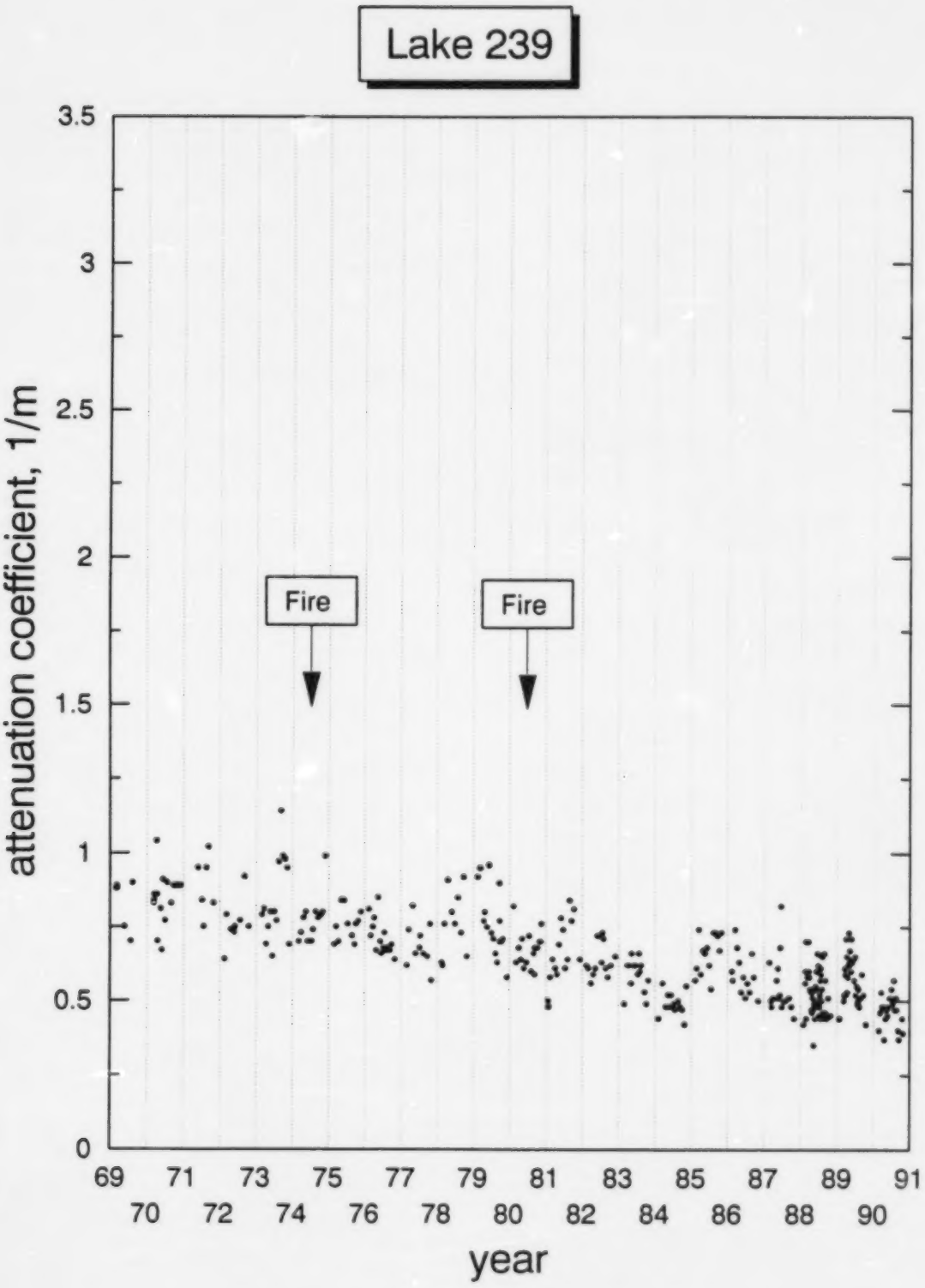

Lake 226 North Basin
150Kg N, 290Kg C, 28Kg P
Fire
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69 71 73 75 77 79 81 83 85 87 89 91
70 72 74 76 78 80 82 84 86 88 90
year

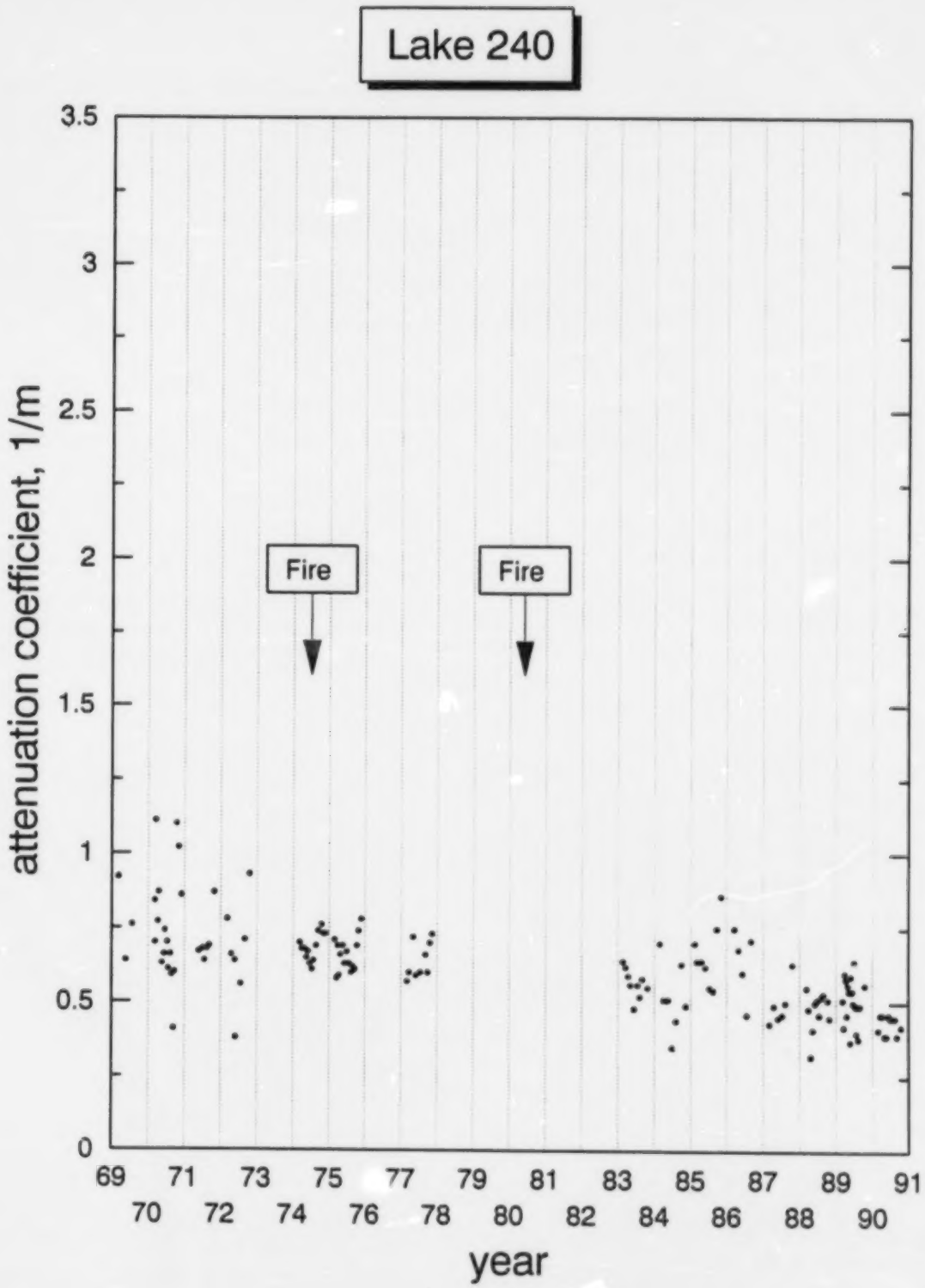

Lake 226 South Basin
150Kg N, 290Kg C
Fire
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year

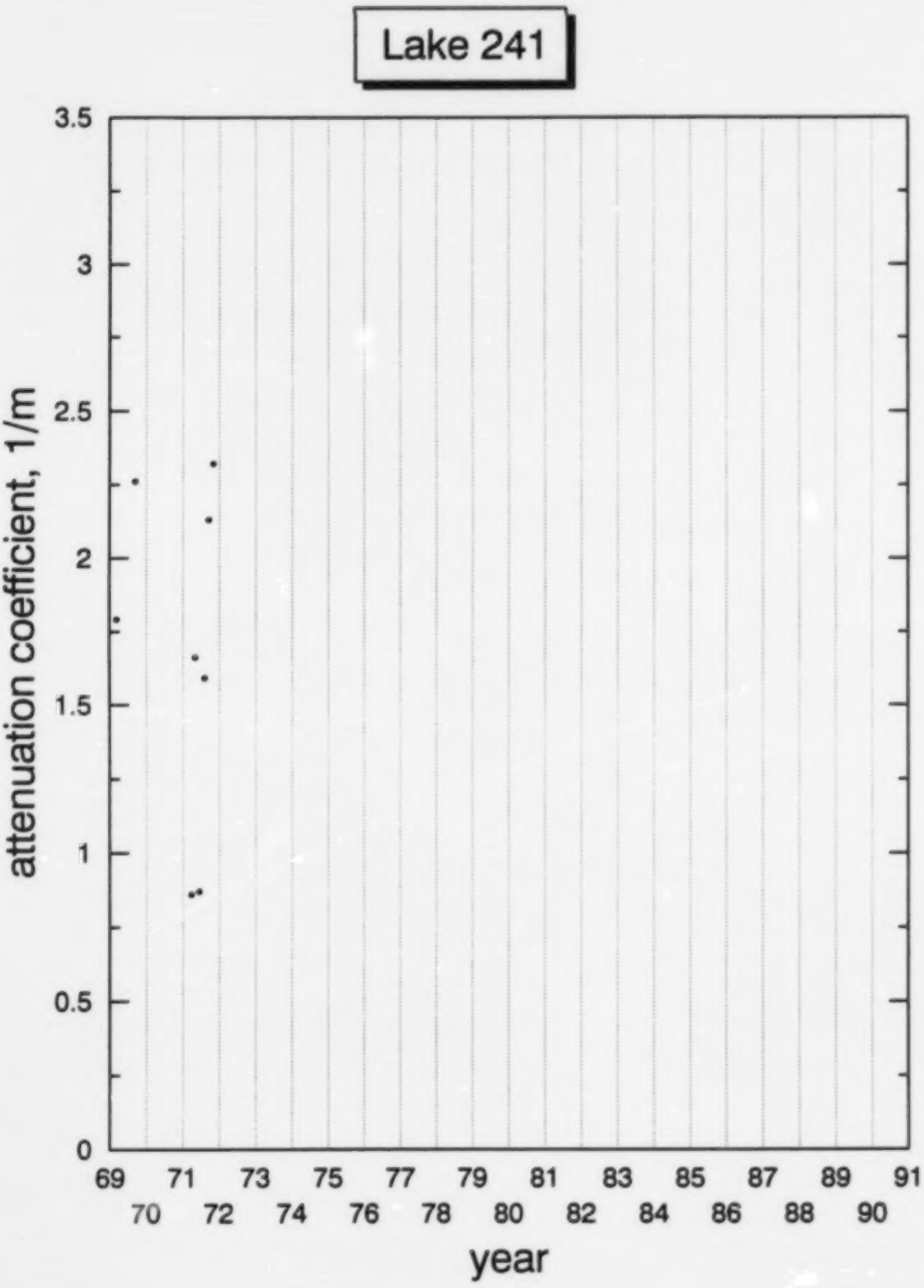

Lake 227
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69 71 73 75 77 79 81 83 85 87 89 91
70 72 74 76 78 80 82 84 86 88 90
year
112.2Kg N, 22.8Kg P
315Kg N, 24Kg P
255Kg N, 20Kg P
22.8Kg P

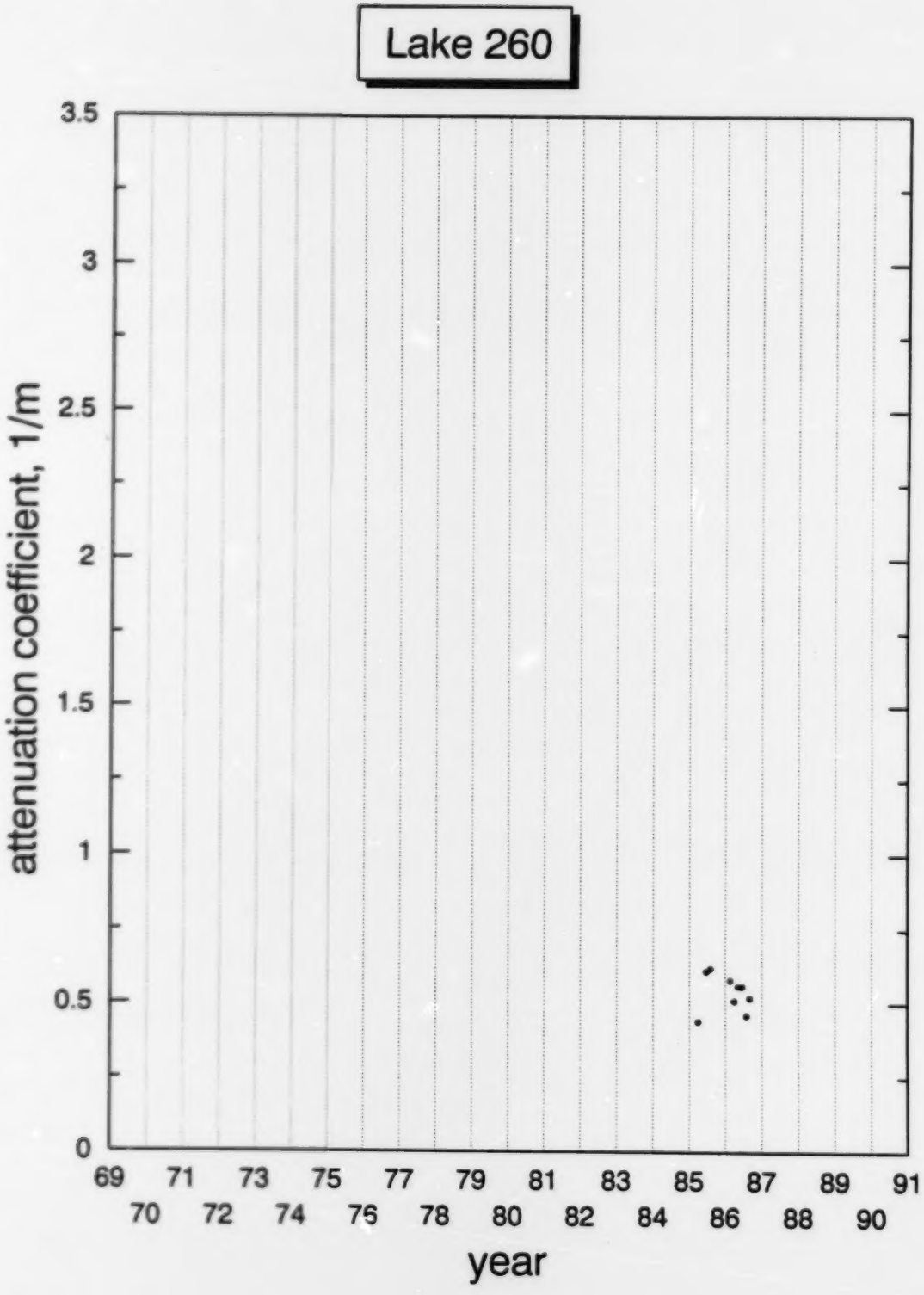

Lake 228
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year

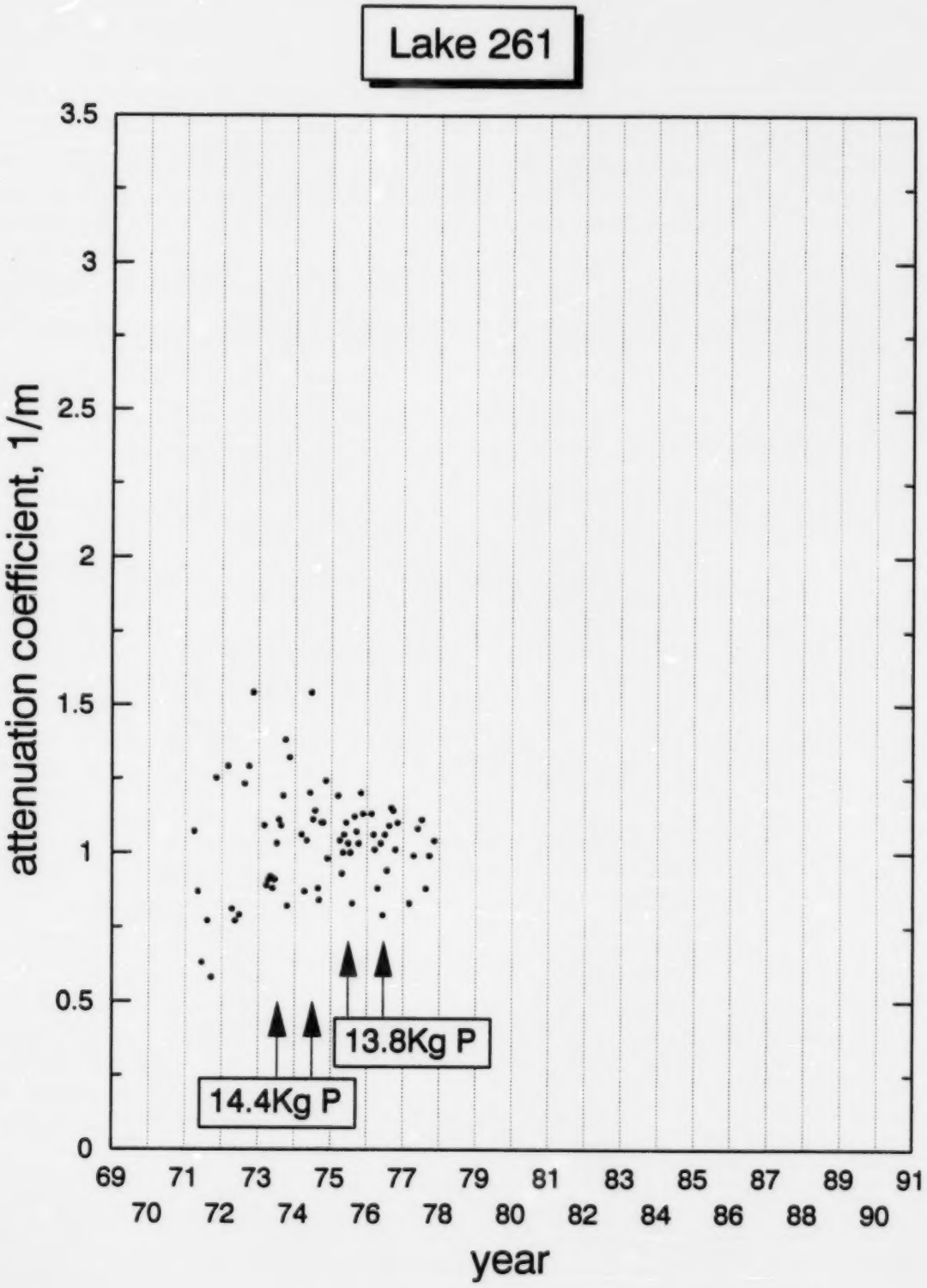

Lake 230
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year
119.8Kg N, 8.2Kg P (under ice)
89.6Kg N, 8.2Kg P (under ice)

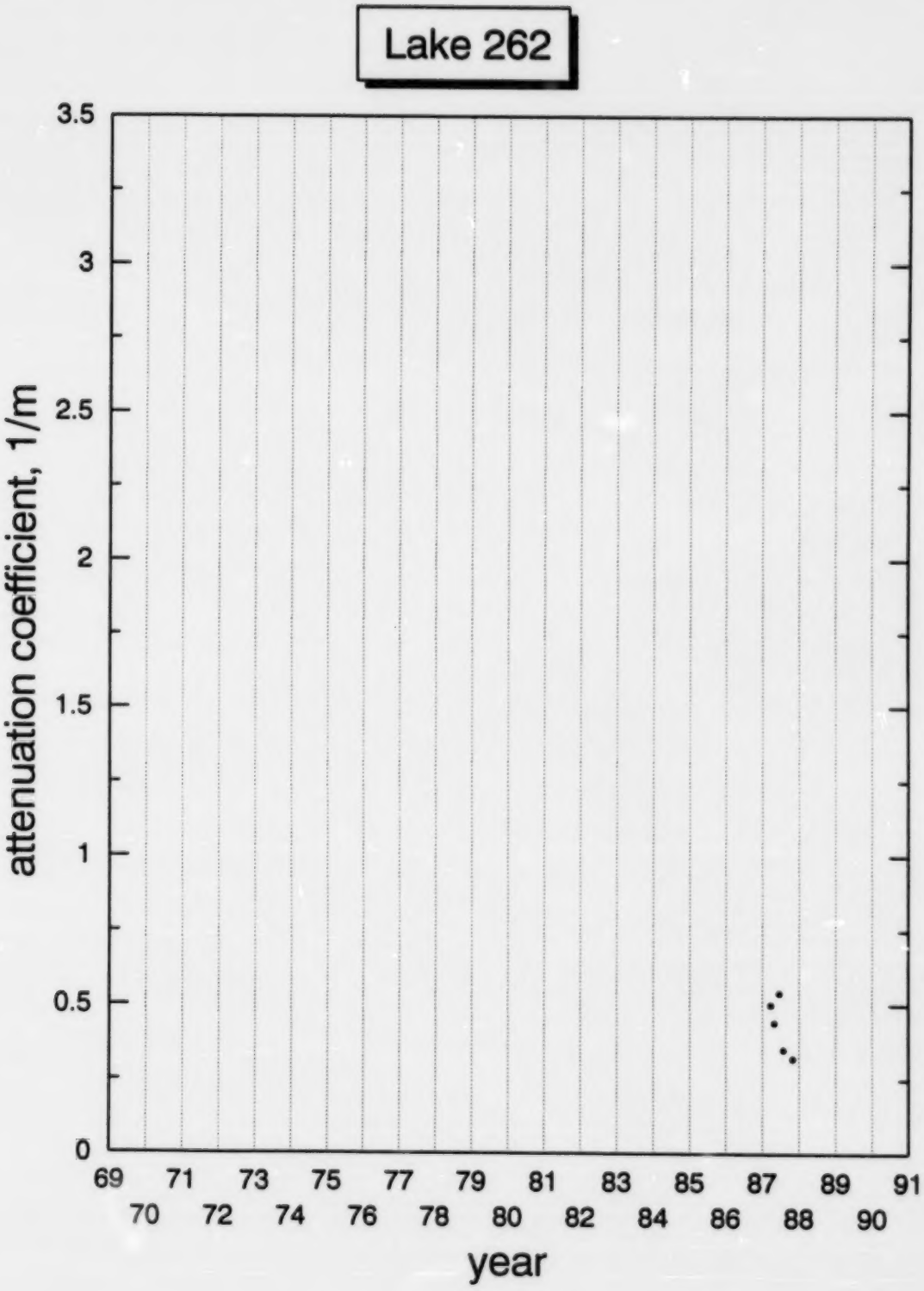

Lake 239
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
Fire
Fire
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year

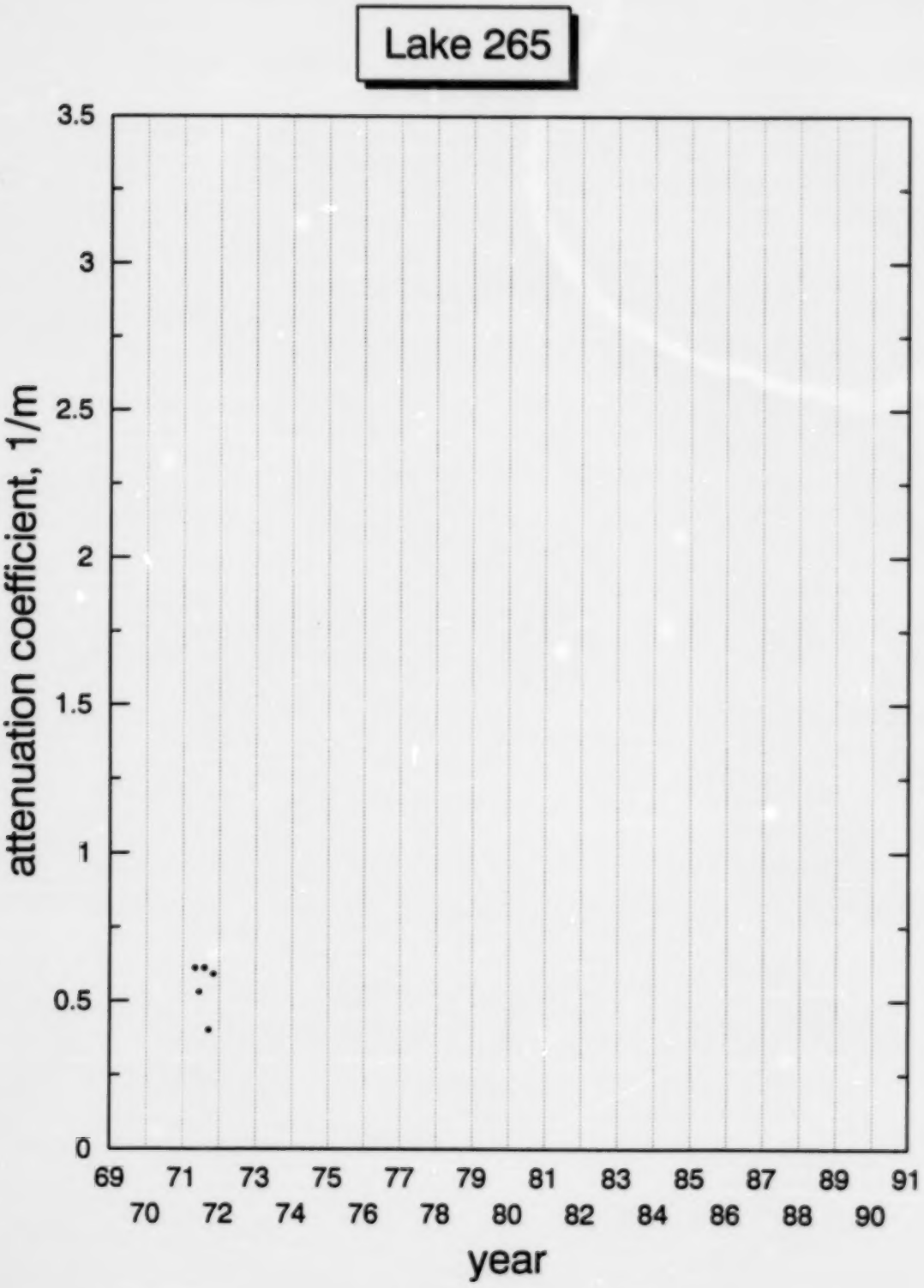

Lake 240
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
Fire
Fire
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year

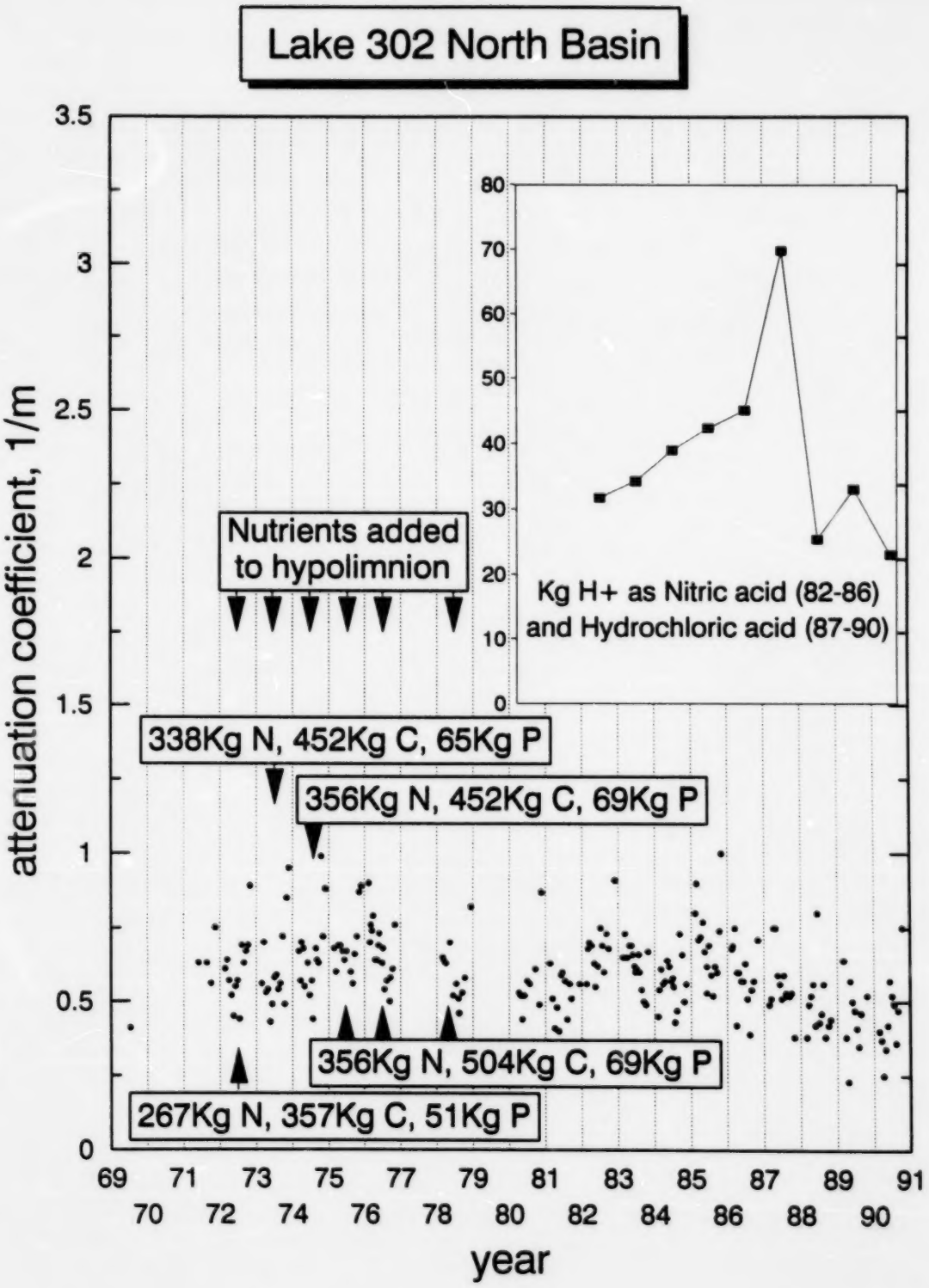

Lake 241
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year

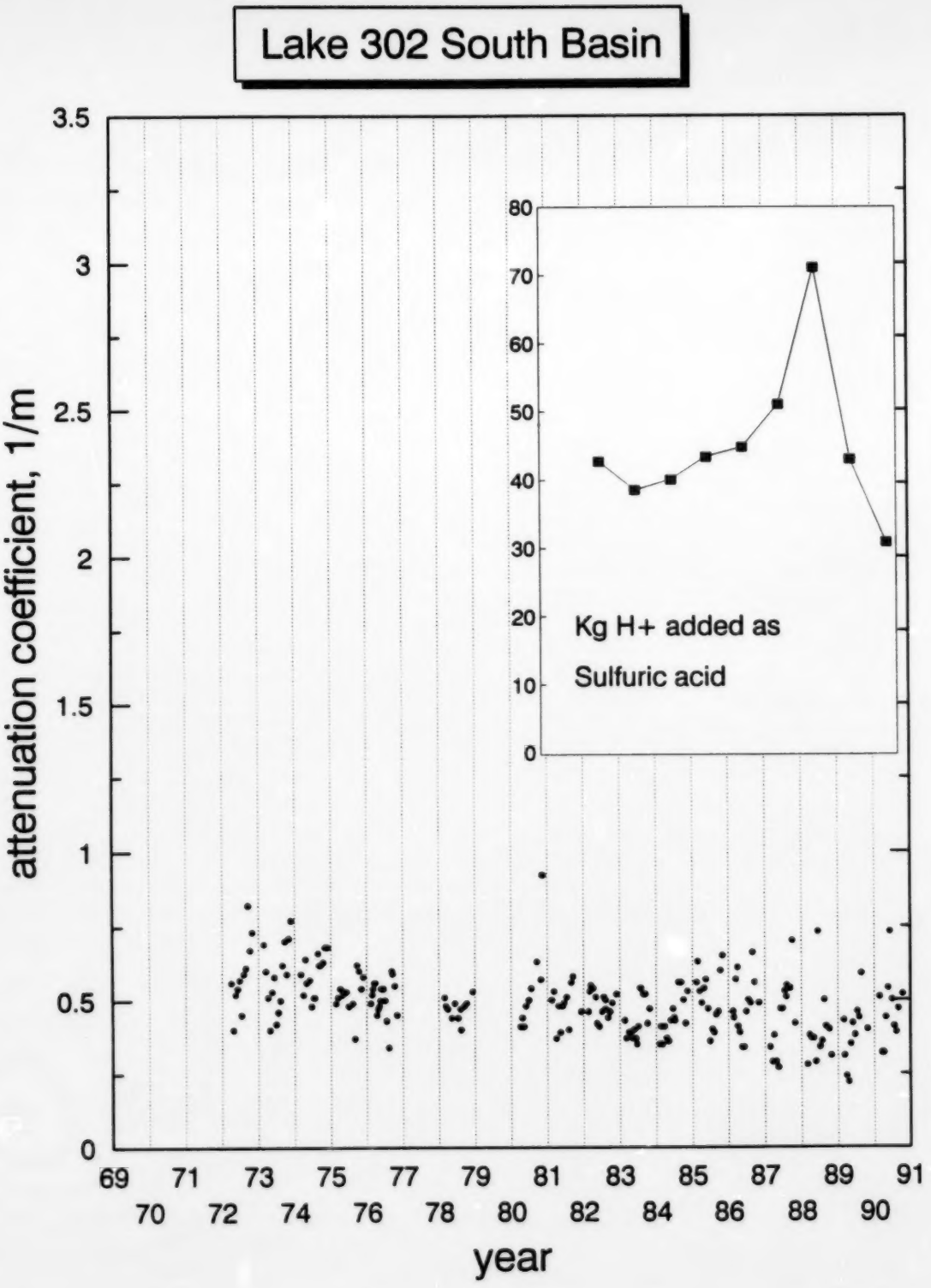

Lake 260
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69 71 73 75 77 79 81 83 85 87 89 91
70 72 74 76 78 80 82 84 86 88 90
year

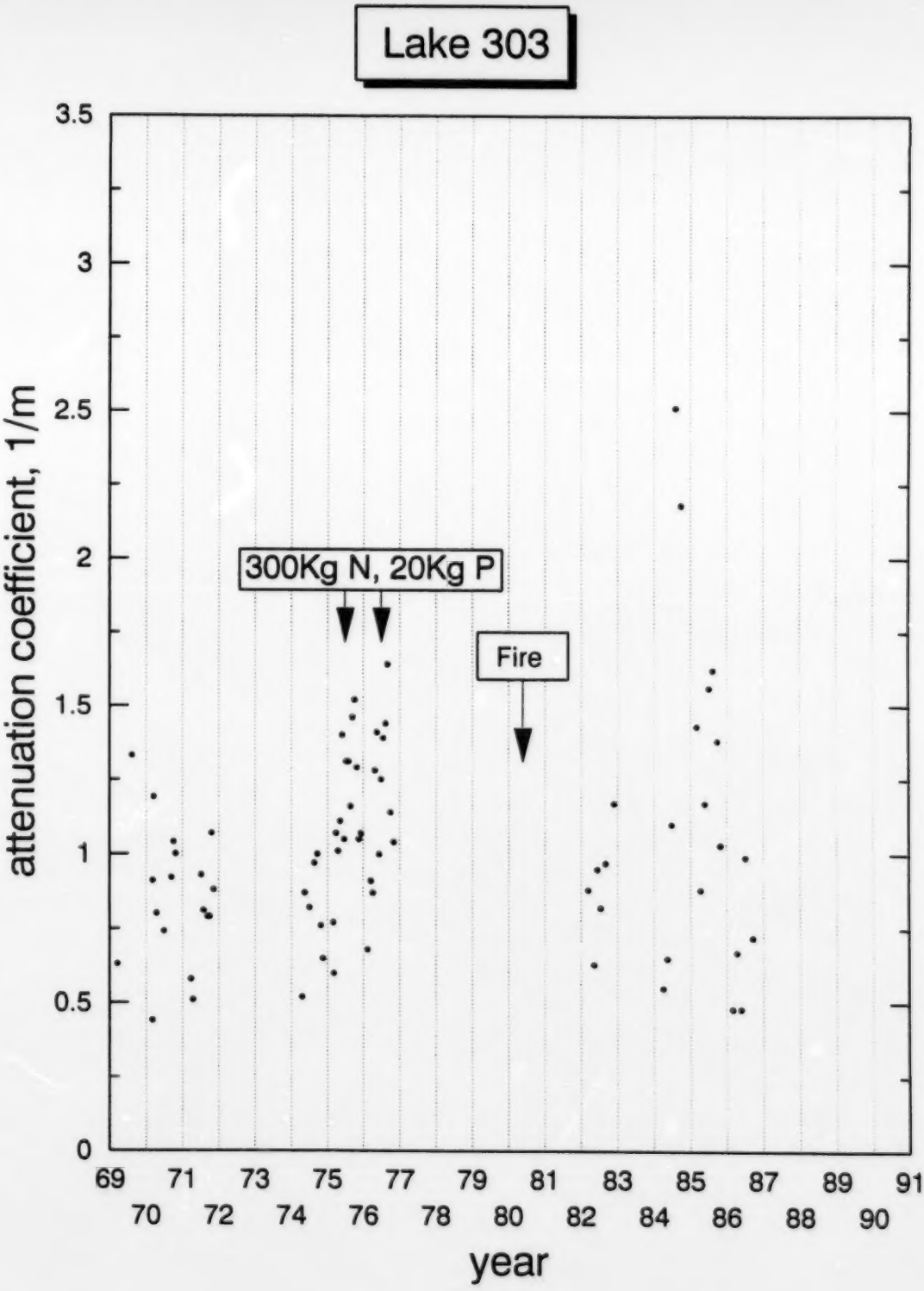

Lake 261
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69 71 73 75 77 79 81 83 85 87 89 91
70 72 74 76 78 80 82 84 86 88 90
year
13.8Kg P
14.4Kg P

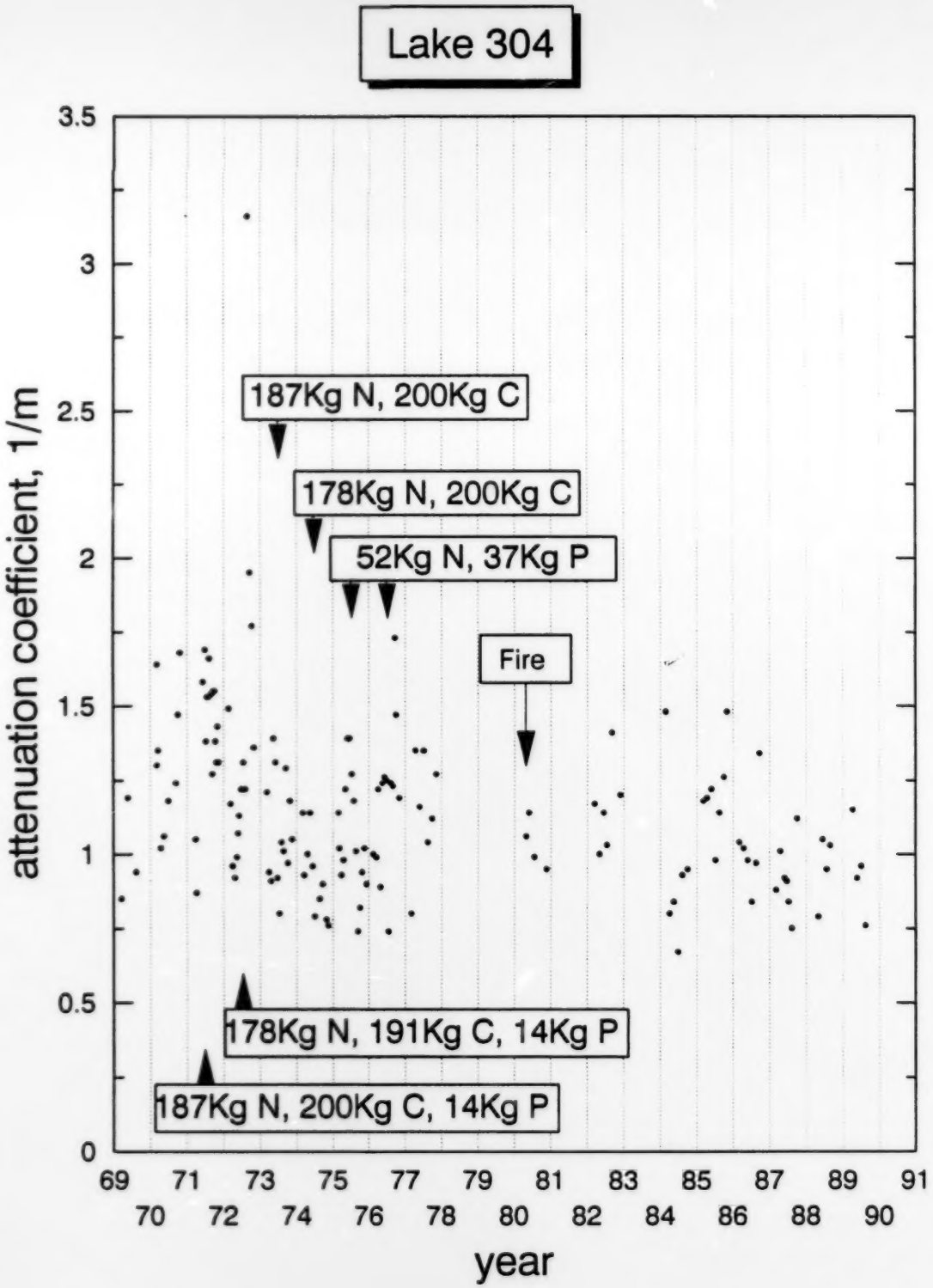

Lake 262
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year

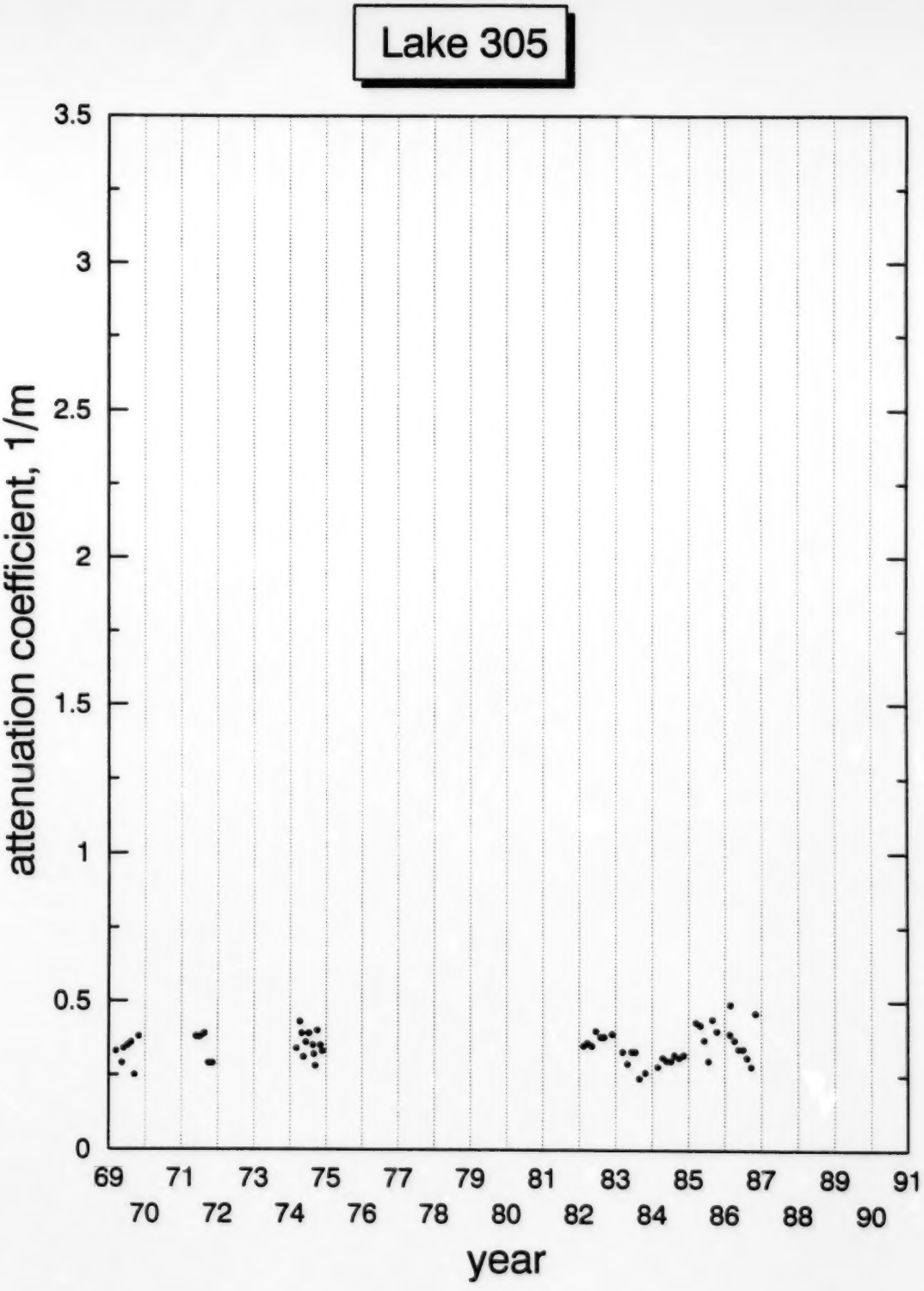

Lake 265
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year

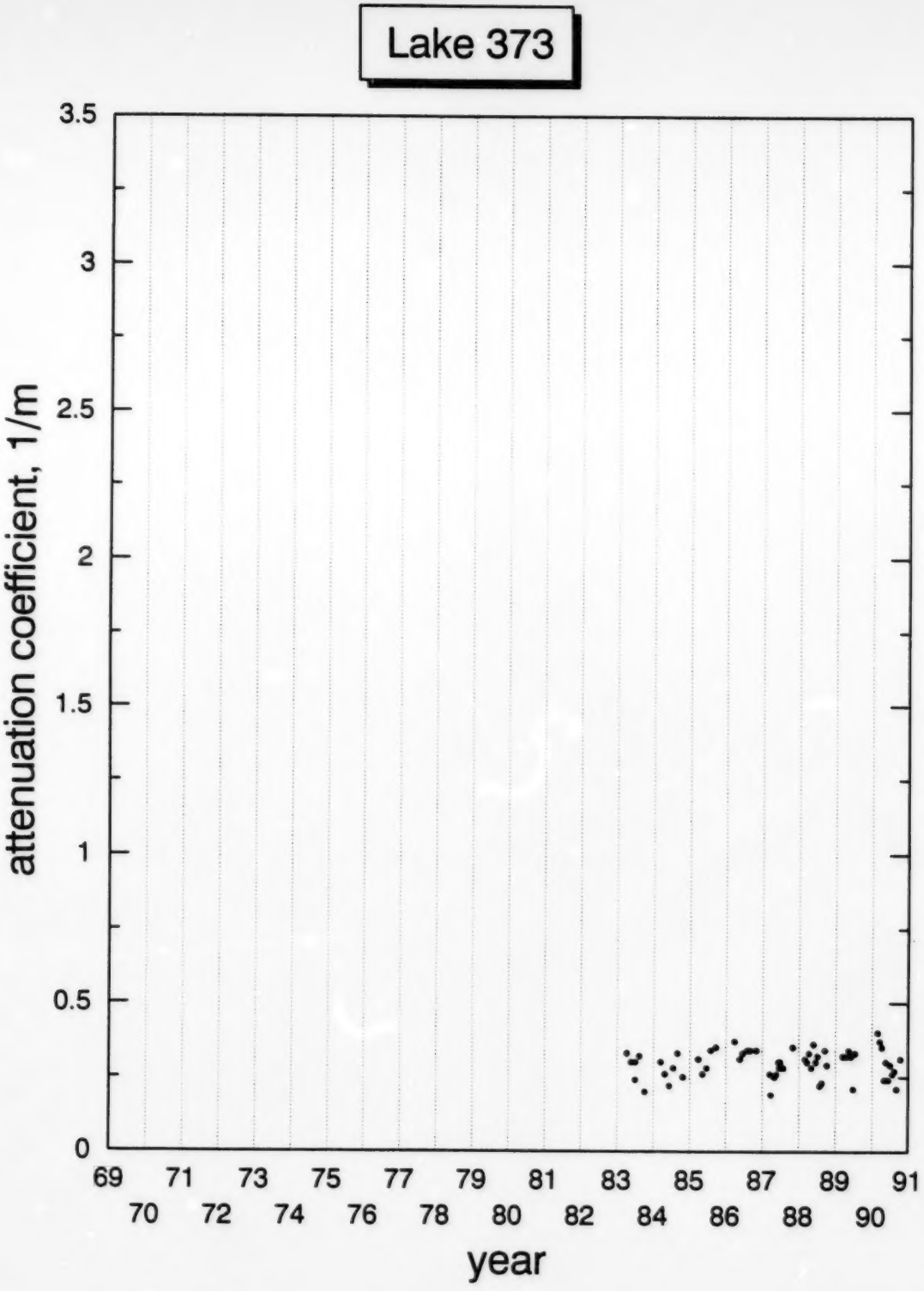

Lake 302 North Basin
attenuation coefficient, 1/m
year
Nutrients added to hypolimnion
Kg H+ as Nitric acid (82-86) and Hydrochloric acid (87-90)
338Kg N, 452Kg C, 65Kg P
356Kg N, 452Kg C, 69Kg P
356Kg N, 504Kg C, 69Kg P
267Kg N, 357Kg C, 51Kg P
0
0.5
1
1.5
2
2.5
3
3.5
10
20
30
40
50
60
70
80
69 71 73 75 77 79 81 83 85 87 89 91
70 72 74 76 78 80 82 84 86 88 90

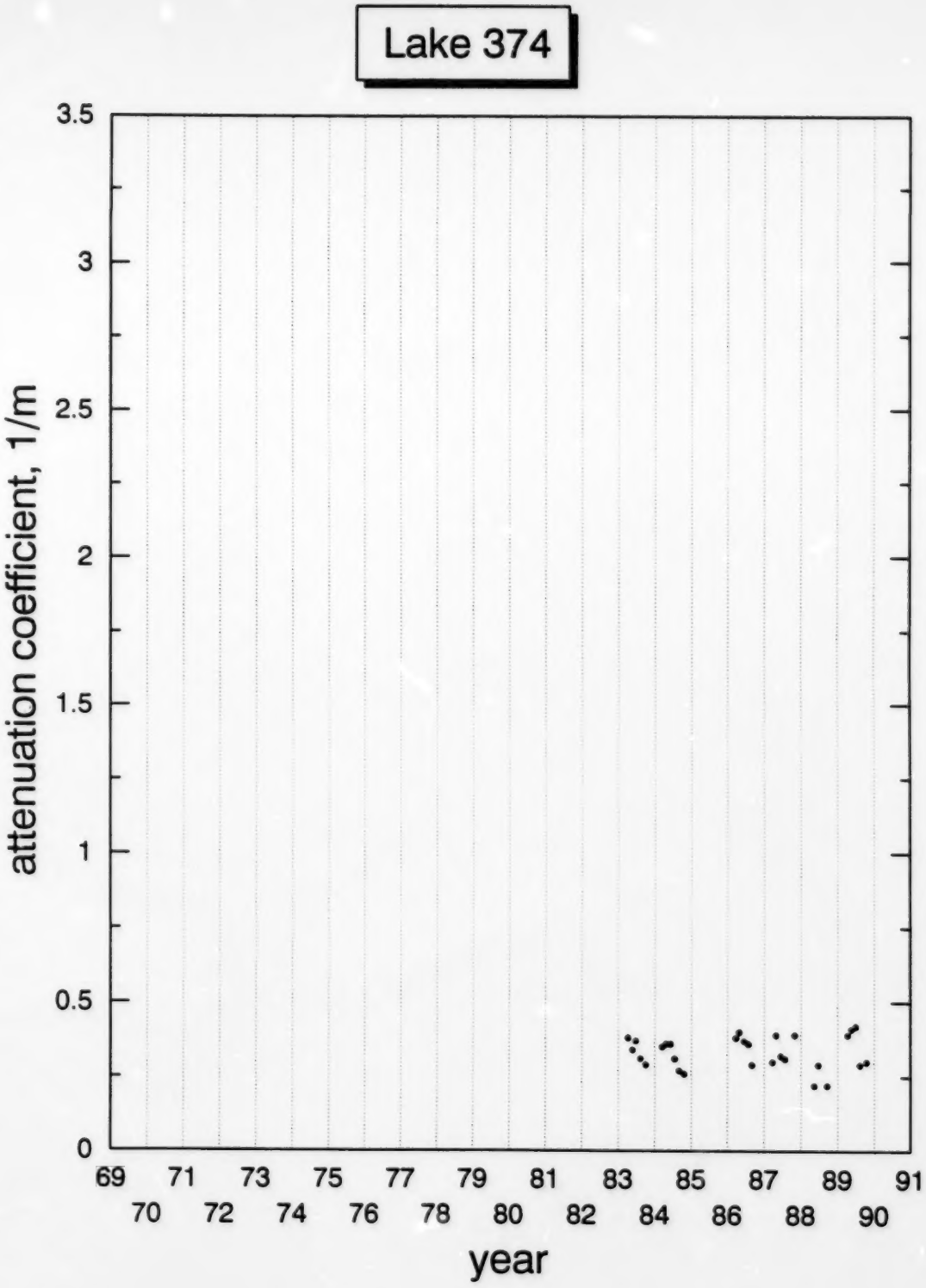

Lake 302 South Basin
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year
80
70
60
50
40
30
20
10
0
Kg H+ added as
Sulfuric acid

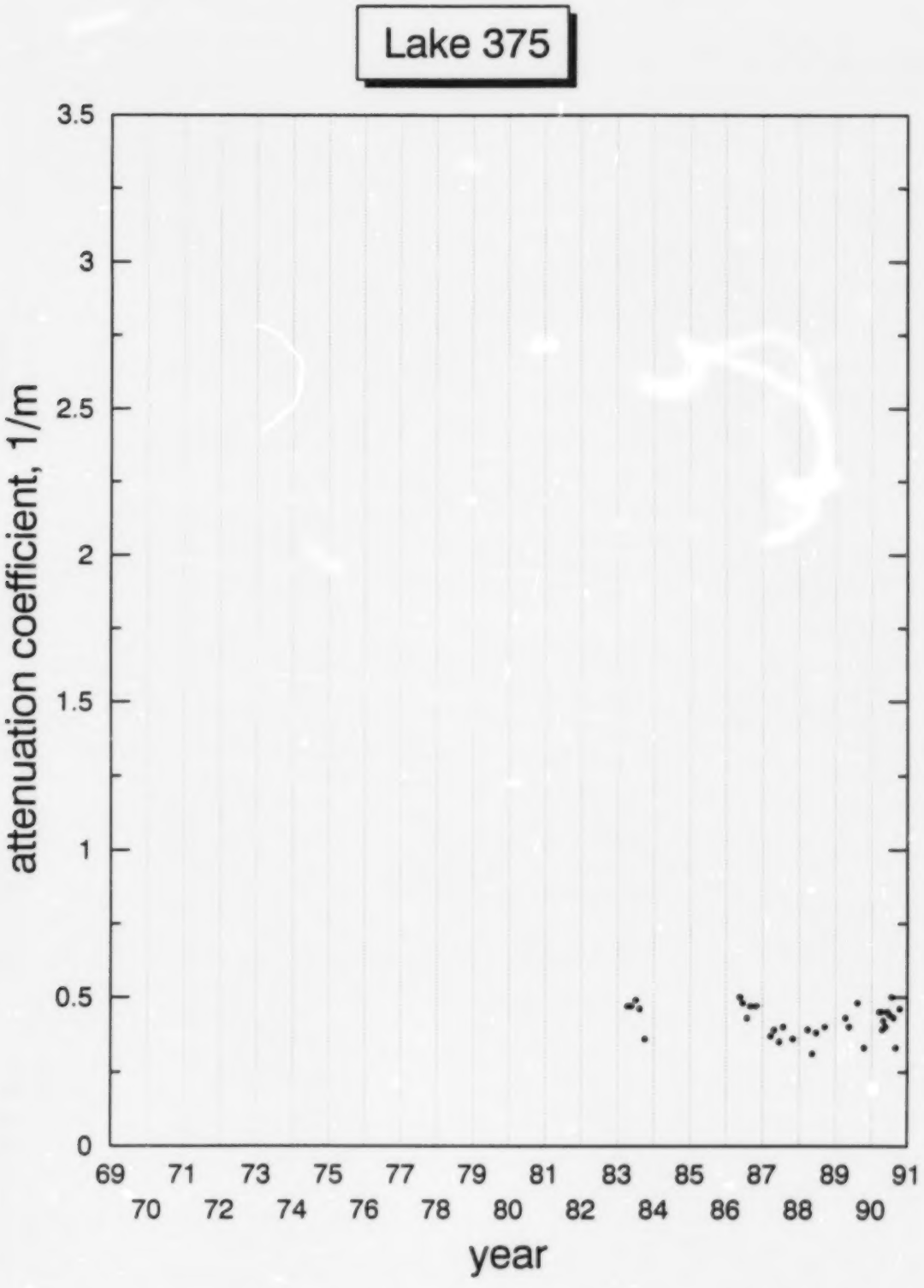

Lake 303
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
300Kg N, 20Kg P
Fire
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year

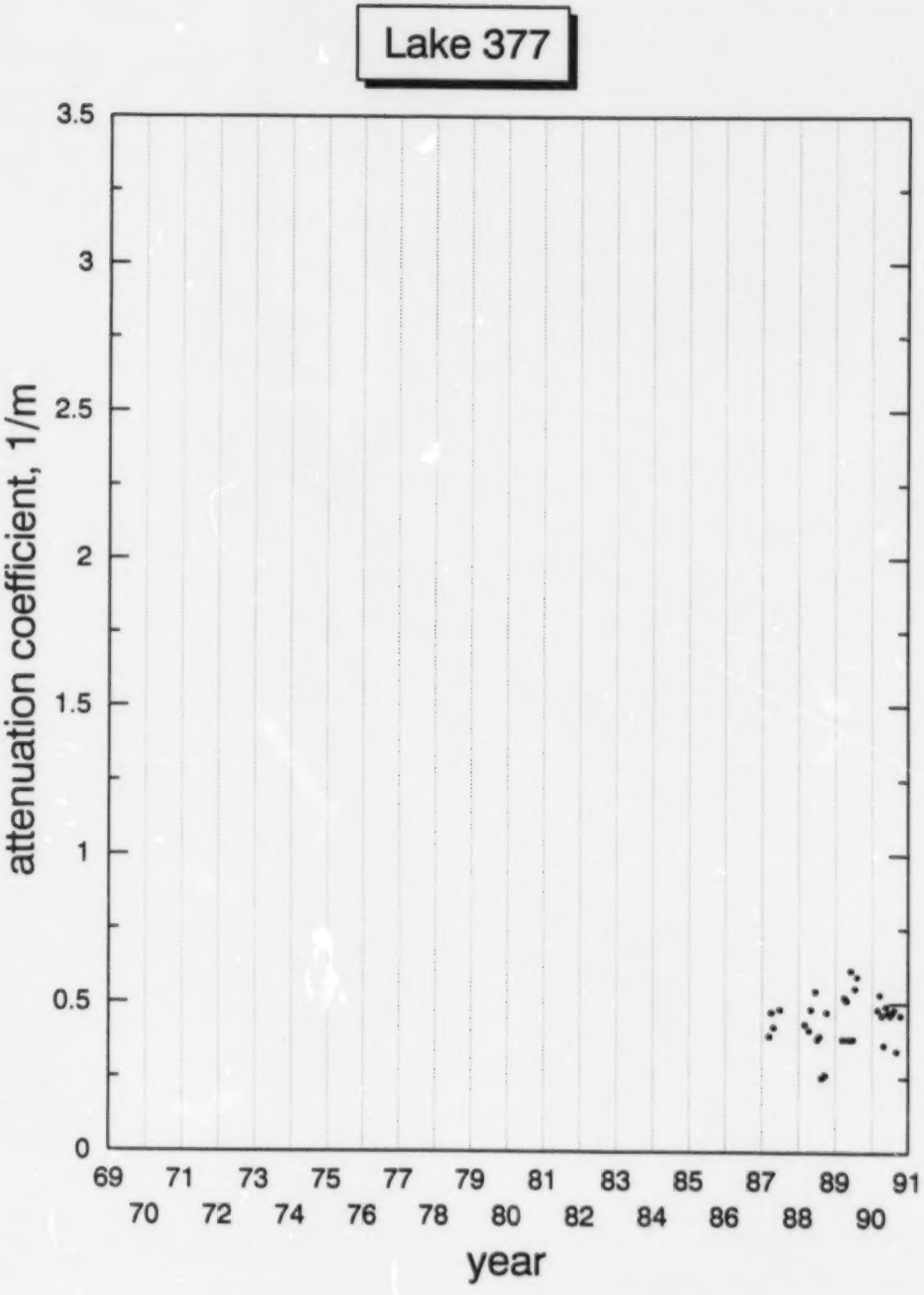

Lake 304
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
187Kg N, 200Kg C
178Kg N, 200Kg C
52Kg N, 37Kg P
Fire
178Kg N, 191Kg C, 14Kg P
187Kg N, 200Kg C, 14Kg P
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year

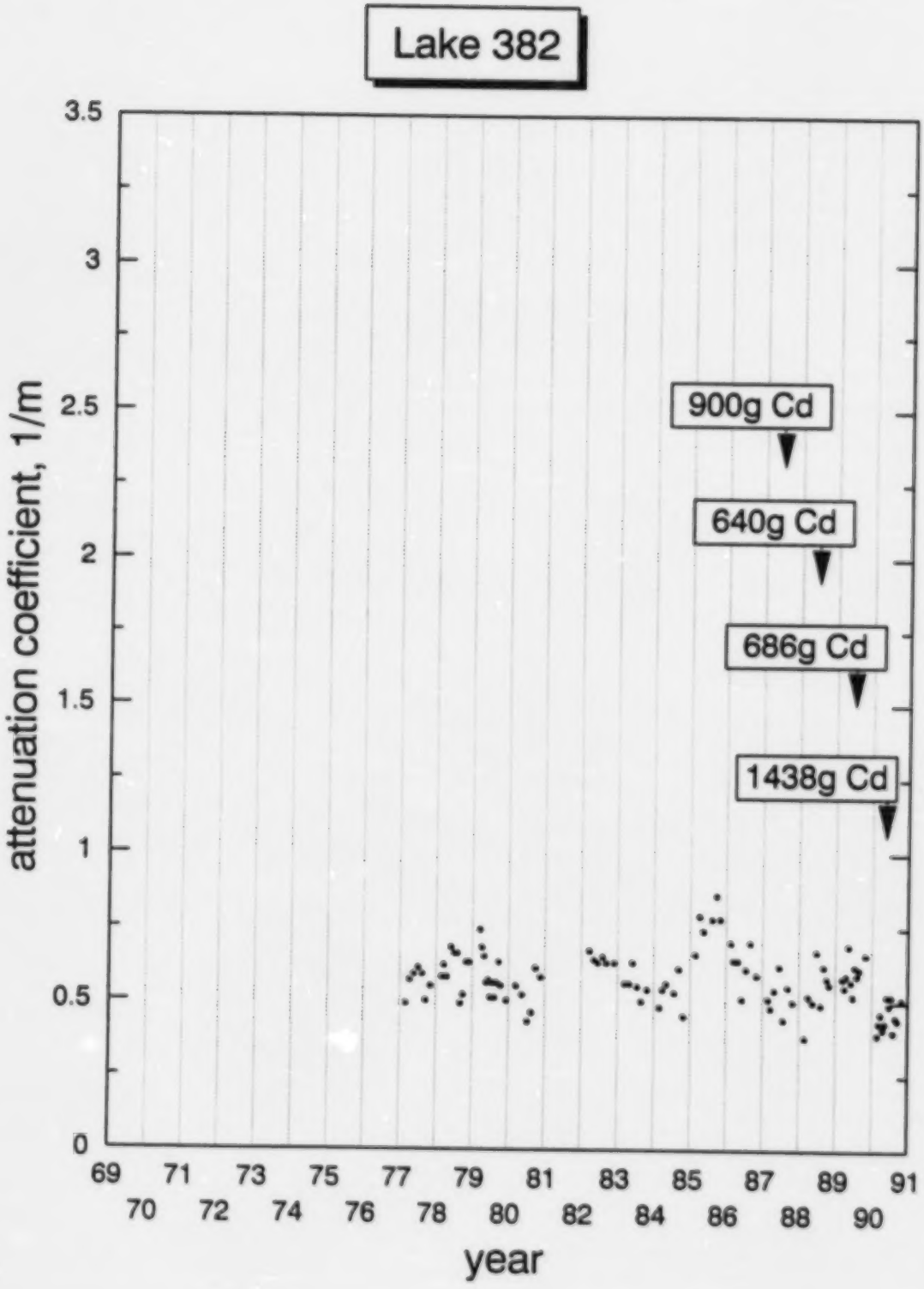

Lake 305
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year

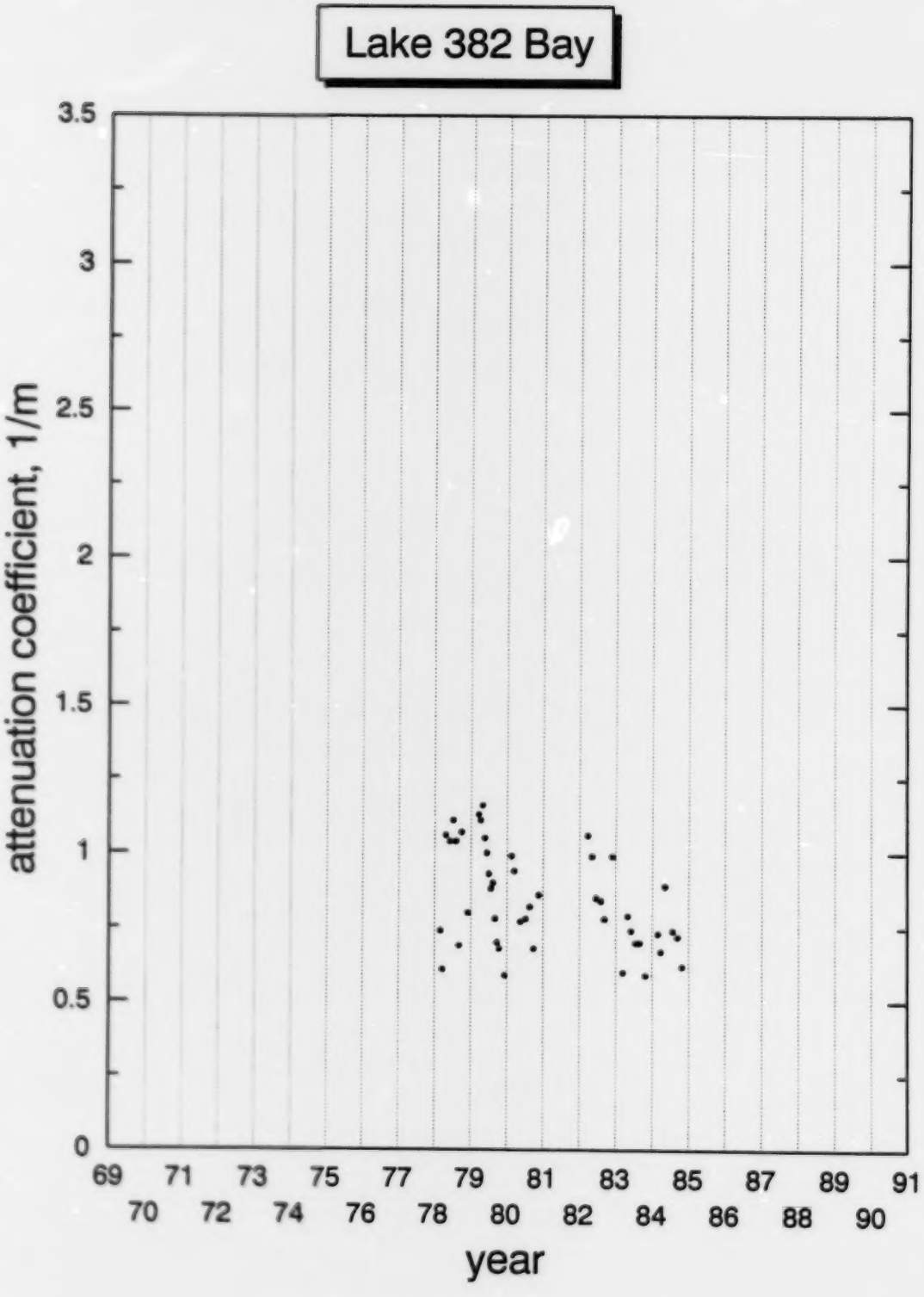

Lake 373
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year

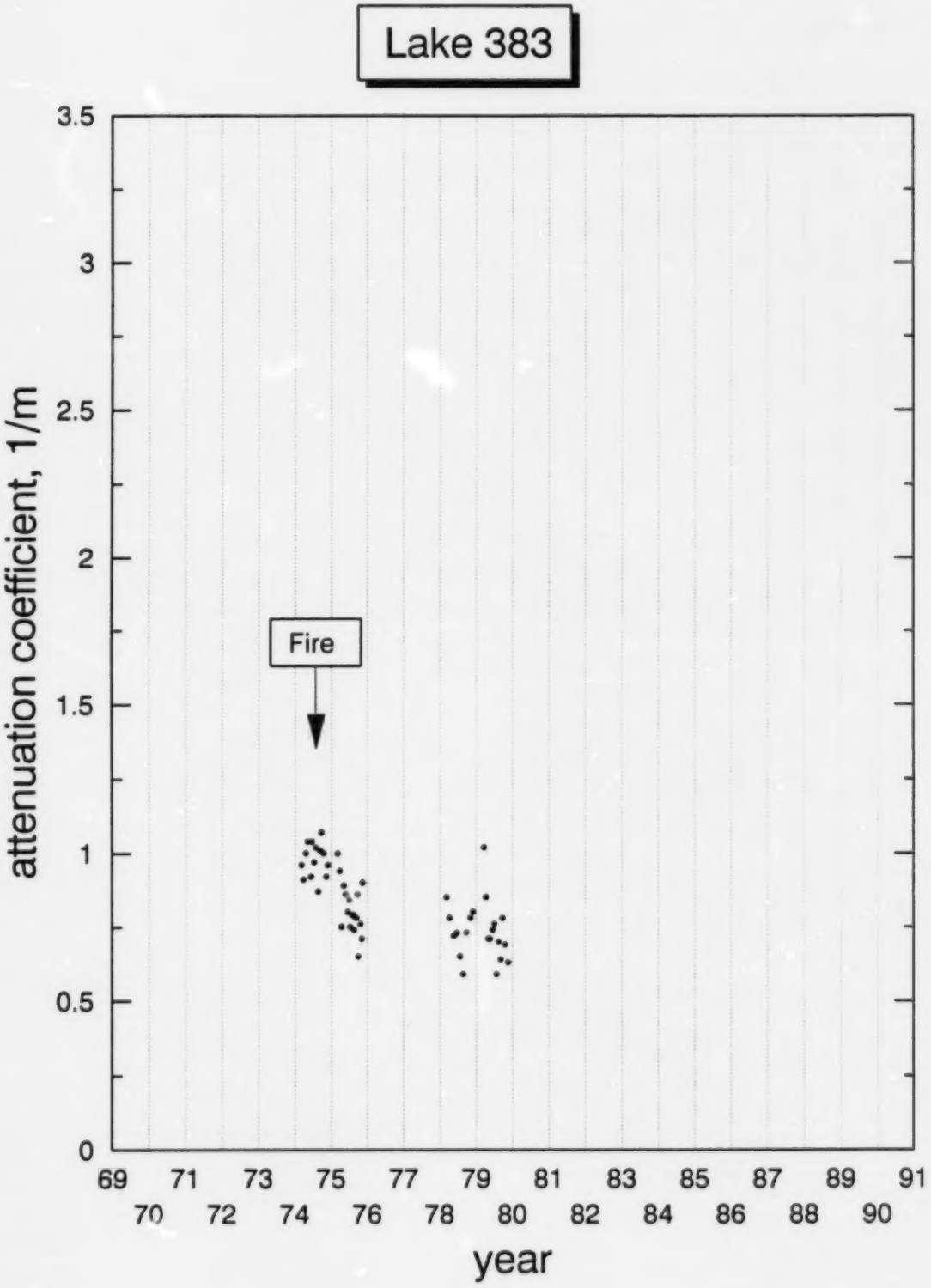

Lake 374
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year

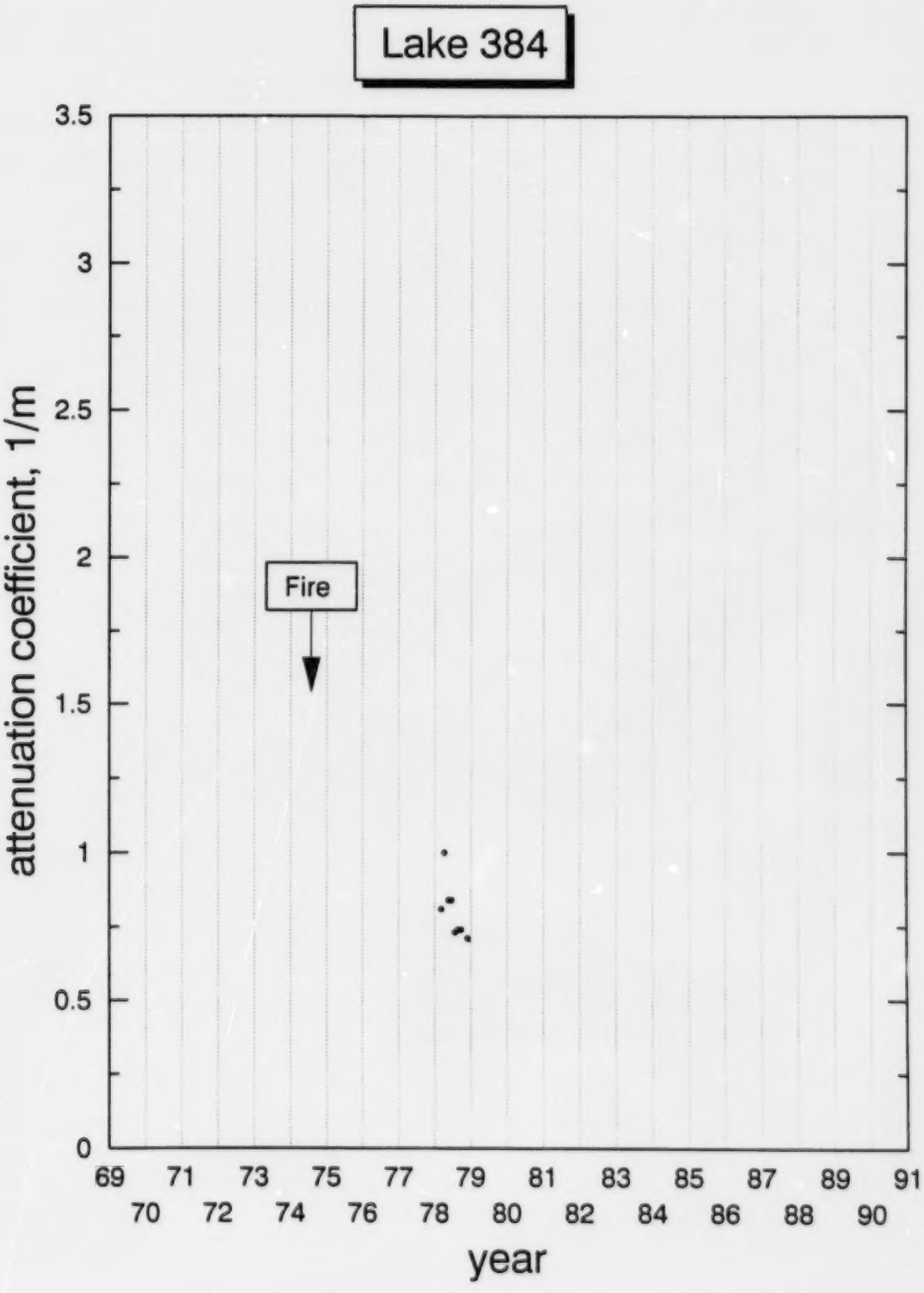

Lake 375
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year

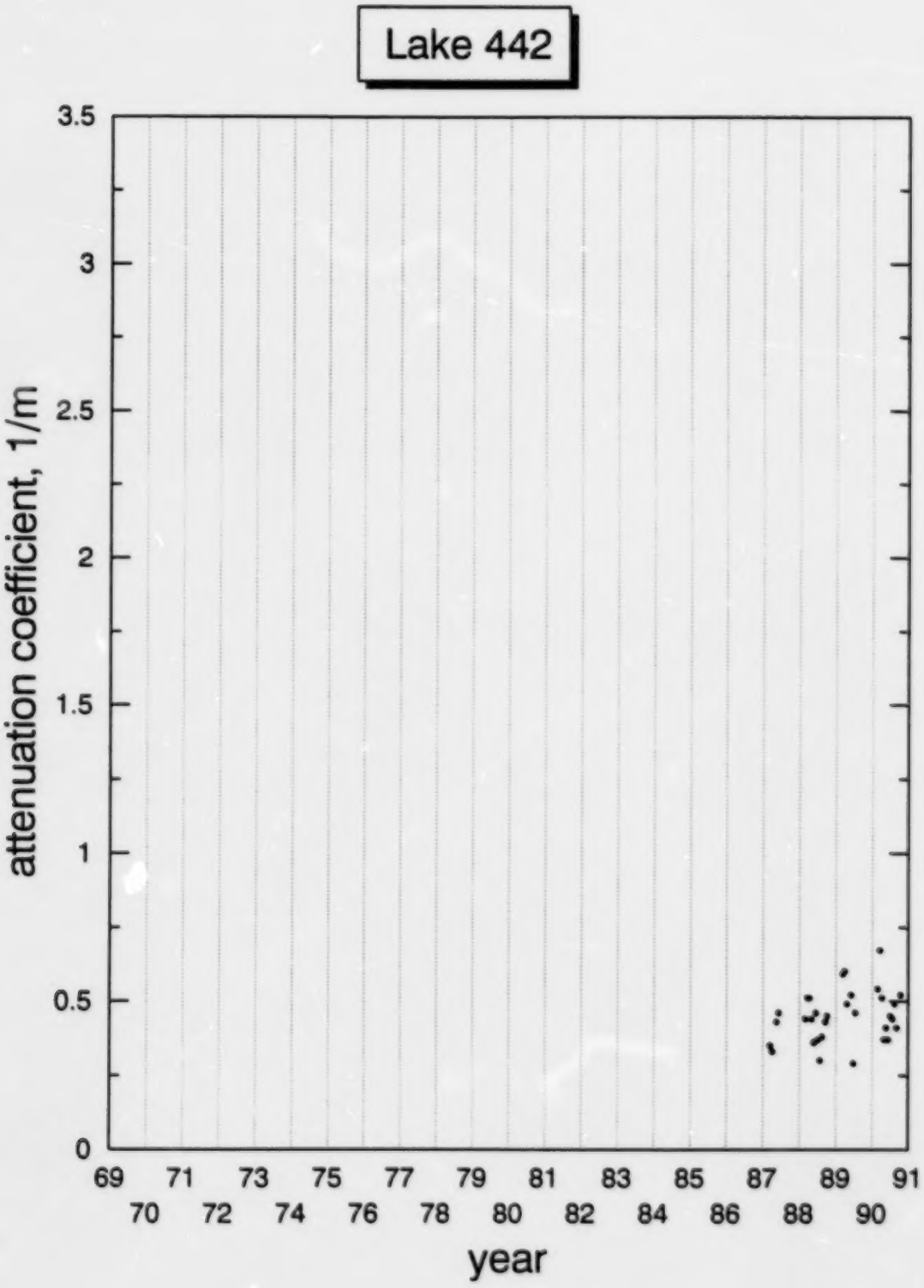

Lake 377
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year

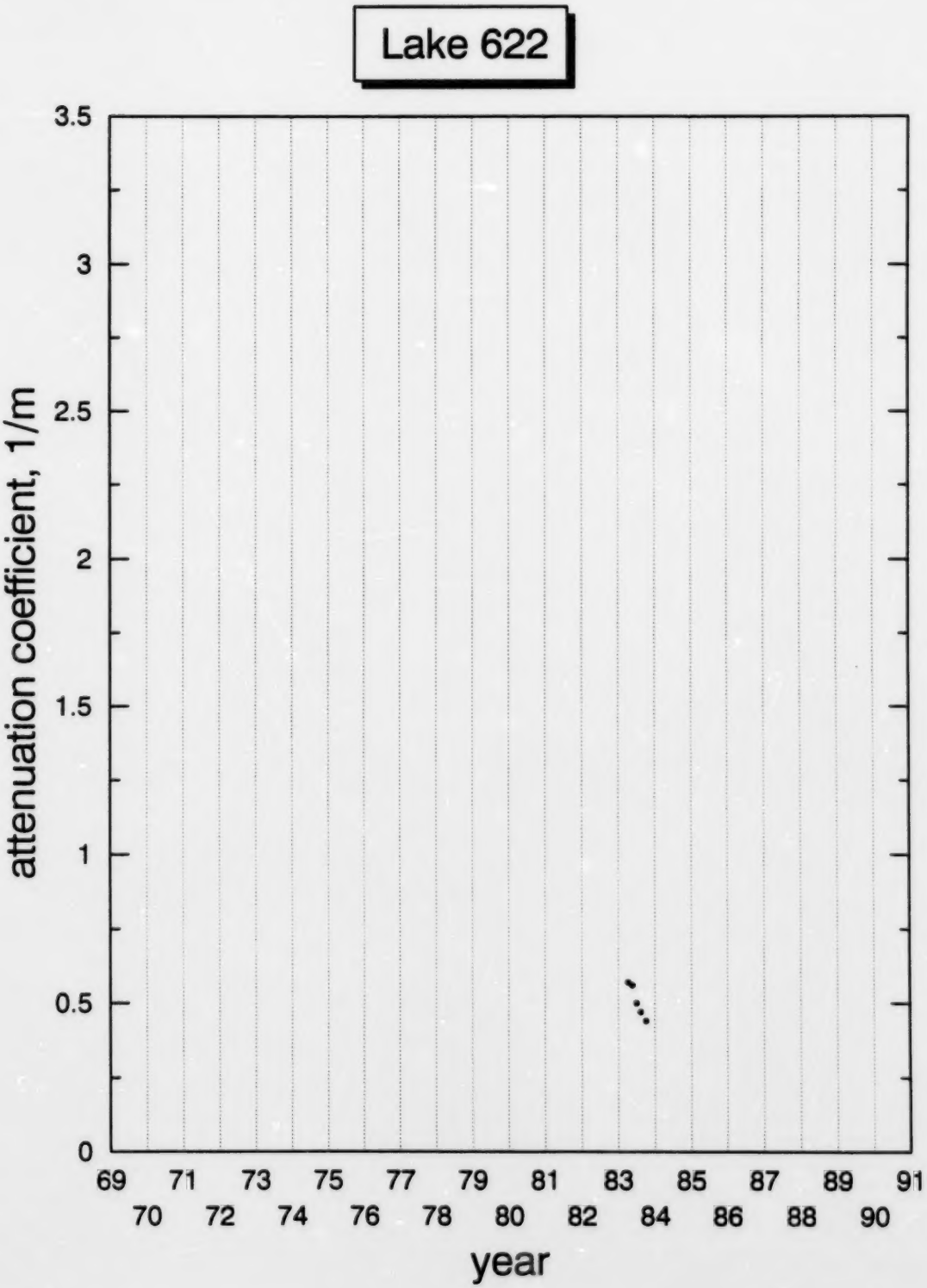

Lake 382
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
900g Cd
640g Cd
686g Cd
1438g Cd
69 71 73 75 77 79 81 83 85 87 89 91
70 72 74 76 78 80 82 84 86 88 90
year

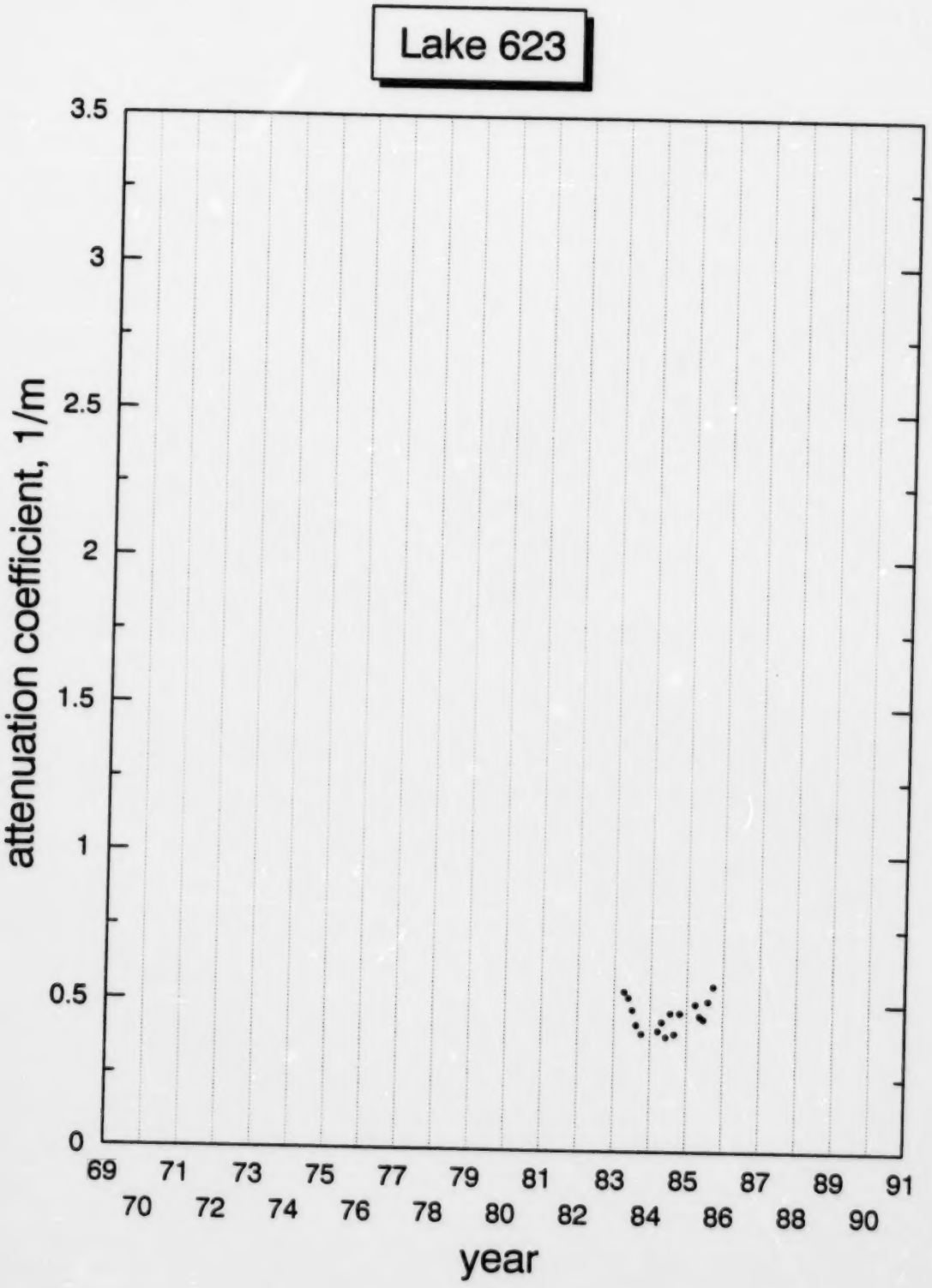

Lake 382 Bay
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year

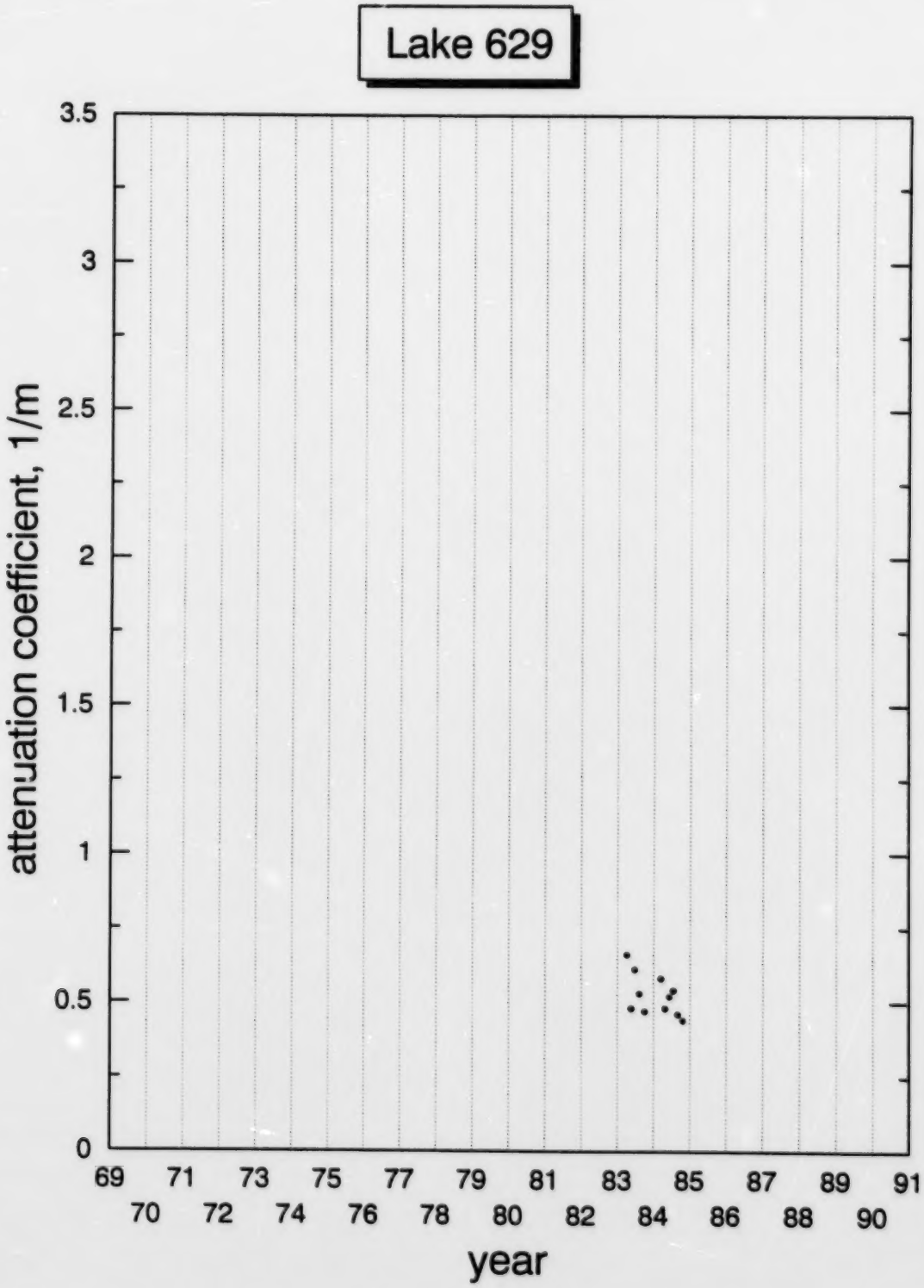

Lake 383
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
Fire
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year

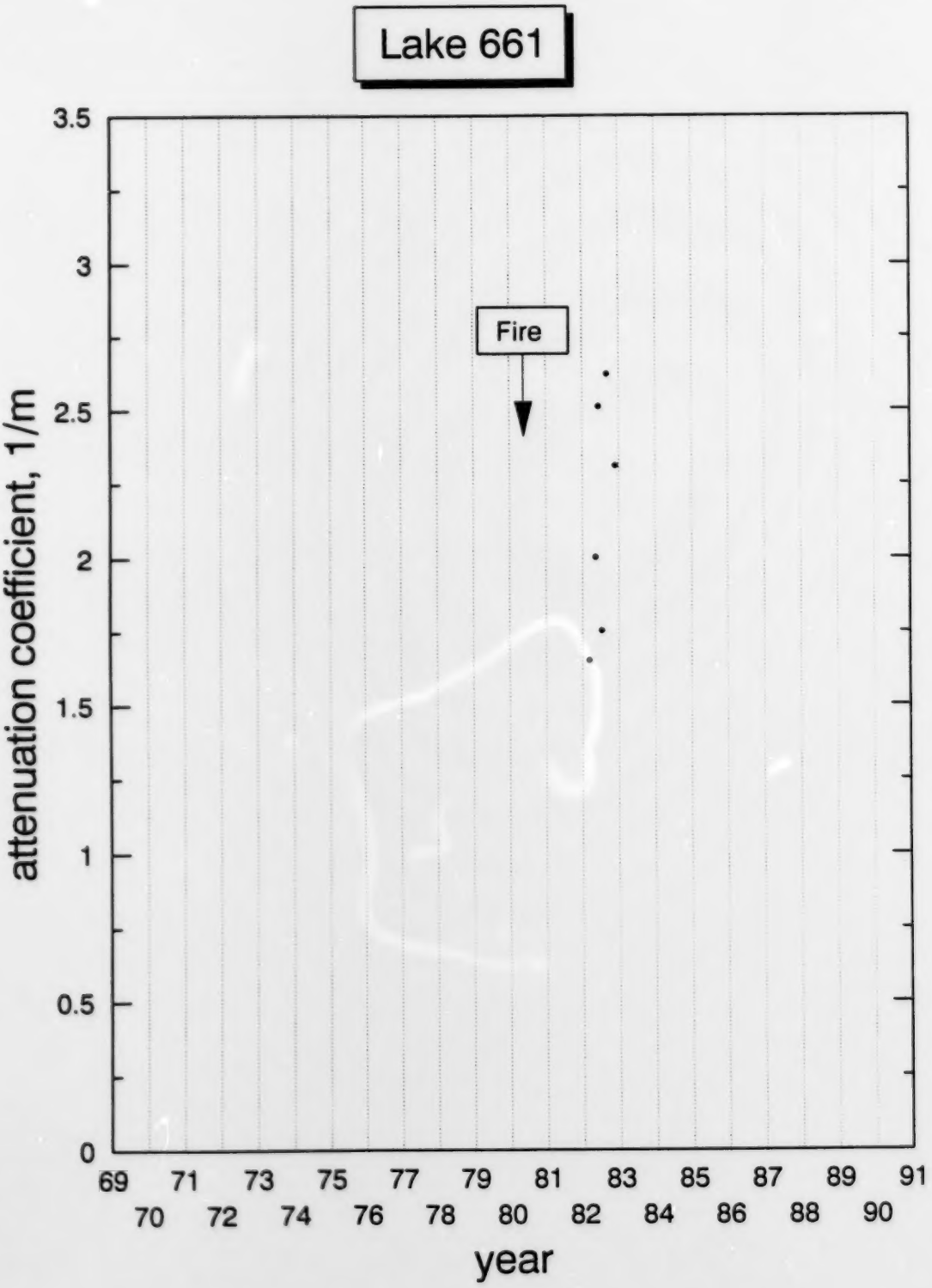

Lake 384
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
Fire
69 71 73 75 77 79 81 83 85 87 89 91
70 72 74 76 78 80 82 84 86 88 90
year

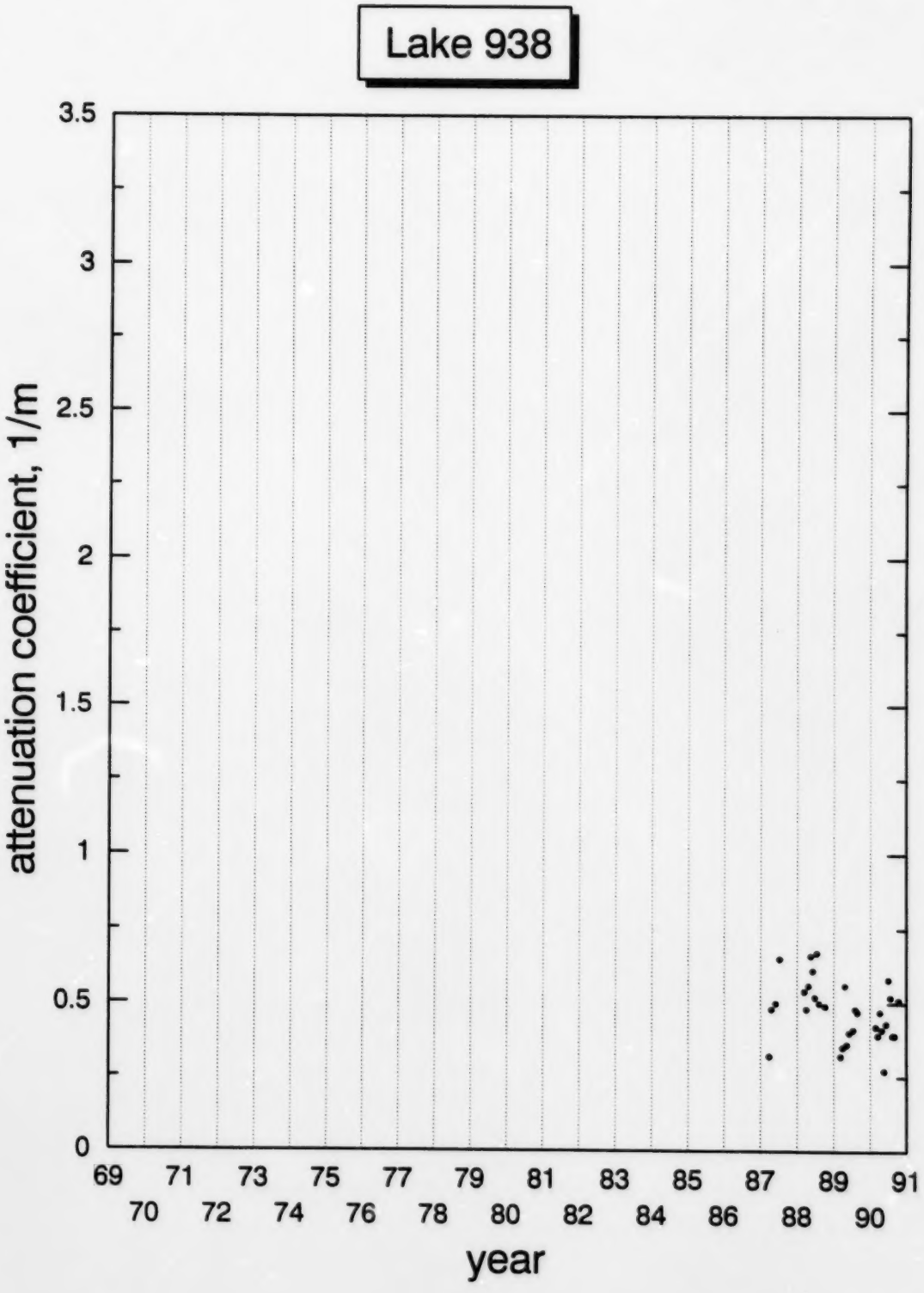

Lake 442
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69 71 73 75 77 79 81 83 85 87 89 91
70 72 74 76 78 80 82 84 86 88 90
year


Lake 622
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69 71 73 75 77 79 81 83 85 87 89 91
70 72 74 76 78 80 82 84 86 88 90
year


Lake 623
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year


Lake 629
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year


Lake 661
Fire
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year


Lake 938
attenuation coefficient, 1/m
3.5
3
2.5
2
1.5
1
0.5
0
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
year